The past year also saw the introduction of sheet metal for exterior side-wall panels, and the controversy between the proponents of steel and other materials is perhaps the keenest of all. It has been said that metal panels have not been adopted more generally because few manufacturers have the equipment to handle them. I doubt if this opinion is true in all cases. Some of the oldest producers are not yet convinced that metal has merits to justify adoption. A purely metal panel calls for more than ordinary attention to insulation; otherwise the trailer will become exceedingly hot. Various insulating methods are employed. Spraying the inner surface with an insulating and sound-deadening material is one of them. Filling the space between exterior and interior panels with mineral wools is another. A practice which at least three producers are using is to use a very light gage metal and back it with plywood or composition board. Usually the backing is glued to the metal under pressure. This construction is claimed to overcome excessive heating and to provide a very strong wall.

Arguments for Non-Metal Construction

The arguments raised in favor of metal, whether it be sheet steel, galvanized steel, or aluminum, are similar to those advanced for automobile bodies and need no enumeration. Arguments against it are less well known, and are based upon the following contentions:

The construction of a trailer differs radically in basic conception from that of an automobile. Wall surfaces should have insulating qualities, light weight, and they need not withstand collision forces to the same degree as the automobile because they need not be occupied while in motion. The problem of corrosion can be solved with galvanizing, but the contraction and expansion of the necessarily large surfaces lead inevitably to waviness.

It has been said by some producers, not using metal, that the public may demand steel because it has been educated to believe that only steel is strong and enduring. If that proves true, then metal will become standard. In the meantime there is a great variety of wall materials. Masonite is most popular; then there are combinations of Masonite and plywood or leatherette, plywood and leatherette, and Presdwood.

All trailers are made with double wall. Sometimes the air space is left dead; other times it is filled with materials like rock or glass wool. Simple roof ventilators are yielding to more complex arrangements, such as a design to permit air to circulate through walls and the use of blowers to force air out through the roof. Cramped quarters and cooking operations demand a positive ventilation.

A great deal has been said about the safety of couplings. It is a matter that is giving highway officials great concern because the breaking loose of trailers is a menace which cannot be tolerated. Authorities are upset by the sight of haywire joining the home-made trailer to a bumper. Trailer and automobile engineers are concerned with the problem of making couplings universally adaptable. The problem of uniting a trailer and an automobile, which were born without knowledge of each other, is sometimes a headache. It has to be solved eventually with reference to both vehicles as is now being undertaken by this Society. Trailer manufacturers have their own ideas of what should be done, but they have been bashful about coming forward.

The problem of proper coupling seems linked inseparably with several other factors, such as proper weight distribution related to both trailer and tow, the requirements for braking, and consideration of the forces involved in both starting and stopping. Some of the trailer manufacturers have made their own tests and have formed some conclusions; car manufacturers also have begun to study the effect of trailers on car operation.

The necessity for exhaustive studies of coupling and braking problems goes far beyond merely making the owner contented. The matter of safety is paramount, and the time is coming when legislation will be demanded. When it does come, it will be wise to know how best to formulate needs. Tire widths may come up for closer scrutiny, since more than one manufacturer has stated that trailers are quite generally under-tired. Certainly, tractive surface belongs in a consideration of brakes and loads.

Trailer weights have increased. The present product runs from 1500 to 2000 lb. and sometimes higher. The desire to leave nothing lacking in the way of fittings and equipment has raised weights to a point where the orthodox two wheels and drawbar are inadequate. Manufacturers are convinced that more rather than less is desired in outfitting; so, to get around the dilemma, they are trying four wheels used in close-coupled manner, or a third or forward wheel accompanying the orthodox two-wheel construction, the third wheel taking the load off the drawbar.

Weight on the drawbar is a controversial matter with little or no fact to go on. Whether weights are too high or not depends somewhat on viewpoint, that is, whether it is car or trailer performance that counts. Perhaps designers need to view trailer and tow as a unit. At the moment it is almost impossible because no trailer producer knows what type of car is destined to do the towing.

Aside from factors peculiar to trailer construction that influence engineering and design, there are two very important ones not so intimately related. One is the function of the trailer; the other is the possibilities of legislation. These seem destined to play a more important role in design trends from now on.

Influence of Function

If one reviews the development of the automobile, it will be recalled that at one time there was little design difference between car, truck, taxi, and bus. Then function or use guided engineering towards a differentiation. The trailer is now at the stage of trying to be all things to all men. This is, of course, a necessary transitional stage. Fundamental design is pretty much the same whether a trailer is to be used for occasional week-end trips, year-around living, or the display of wares, and that design has been adequate until recently. But certainly, as actual road experience multiplies and manufacturers make more effort to analyze where their product succeeds and fails, modifications will appear.

The use factor may seem over-emphasized, but we are forced to consider it when so much is being spoken and written about the trailer as a solution to the housing problem. Trailer manufacturers have said that they are going to get great volume selling to itinerant workers in factory and field. They declare that, if a man working in Detroit in an automobile factory is let out, he can bundle his family into a trailer and head toward whatever city offers employment. A carpenter will hear that there is a housing boom in a nearby State and will proceed there to become employed immediately. Or, again, there are workers who follow the harvesting season from South to North and wish to take their families with them. How does the present-day product fit this market? Does employment follow as a corollary from the ability to move? Can a factory worker purchase a trailer for, say $500,

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even on a time-payment basis, and be assured thereby of steady employment?

The optimist declares that trailer living can be carried on at a fraction of the cost of settled community life and that the payments for rent will purchase a trailer. But this view presupposes that there are to be no increases in taxes, no legislative attempt to make the trailer owner share in the support of the community through which he gets his livelihood. Costs must be reduced drastically before there is any certainty of this mass market, and the work of lowering costs involves much engineering.

The itinerant agricultural worker already has taken to the trailer. He has gone to junk yards for an old automobile axle and a pair of wheels. In some extraordinary manner he lashes the wheels so they won't steer themselves. He gets planks from building wreckage and, from then on, genius burns to produce some of the most interesting contraptions on the road.

The car that tows these contraptions antedates streamlining. It, too, was picked up in a junk yard. Entire outfits – car and trailer – dragging families from field to field don't exceed a $50 investment. Regardless of the fact that the itinerant agricultural worker can escape rent payments with a trailer, what has the manufacturer to offer him that is within his reach? For the cotton picker or wheat harvester to attempt to purchase would be the first step in being plowed under.

It is extremely hazardous to make any prophecies about possible trailer markets, but it has to be done because a study of use can yield much valid material to guide engineering effort. If one examines the development of the automobile, one can see that the use factor has been the guide, and it is always so. It will be so with trailers. No one questions, for instance, that the trailer serves persons who travel from town to town with wares to exhibit. Nor is there much question of the trailer's value as a vacation vehicle if it can be purchased at a reasonable figure. It is doubtful if trailers will become very important as a year-around home proposition, and many producers express this doubt.

The present trailer, with very few exceptions, is being designed for long-term occupancy. 1937 models boast among other things – electric-light plants, hot and cold water, heating and ventilating, better bathing and toilet facilities. But the cost of such a well-equipped trailer runs between $1000 and $1500, which makes it a luxury article unless it does replace rent. Assuming a static state of affairs, year-around living is practical, but nothing is static. Impending legislation threatens to eliminate a large proportion of the economic advantages possible today.

Future Taxation

Taxes will rise in two forms: one to cover the cost of highway use, the other a personal-property tax which may assume the form of a real-estate tax if the trailer is used as a home. Then will come strict zoning. Even now in States where the trailer moves in numbers, stopping places are restricted. Travel is banned on certain highways because the trailer is regarded as a truck and treated accordingly. This nuisance, this limitation upon the free use of the trailer, will grow rather than diminish. Flint has banned the trailer within city limits unless it conforms to housing regulations. This is just a whiff of legislation in the making.

Regulation of trailer use may be far more influential upon its development than engineering requirements. About all that highway officials ask is that trailers have adequate brakes (which are slowly coming about without official edict), clearance lights, mirrors to reveal the army of impatient motorists waiting to pass, couplings that won't uncouple themselves, toilet facilities that will guard the public health, and windows that don't increase trailer width when they are open. Some States talk shatterproof glass. These are not onerous burdens, but they do stand in the way of cheapening the product quickly.

The case against the trailer has been built almost entirely around the home-made contraption. When legislation is promulgated, it will aim at the domestic breed, but it will hit everybody. Authorities alone are aware of what dangerous products are roaming the highways. The Chief of the Texas Rangers has stated that the western part of his State is littered with the bones of trailers that couldn't take it. Stories are current of chopping holes in trailers to release the occupants, and of couplers parting to let trailers disappear into ravines and streams. It is hard to believe but, when a trailer is made without windows and with a single door and it overturns on the door side, it simply cans the occupants.

Sociological Implications

After all, speculation is rather vain, but necessary. It may be that our citizens have deeper nomadic instincts than we realize. Maybe the gift of mobility to homes will prove more valid than now seems reasonable. To go deeply into the sociological implications of trailer living hardly belongs within the province of this paper. Society will accept the trailer in so far as it serves a need; it will penalize it where it proves unsocial. Sensing what it is the trailer has to offer that is unique should canalize engineering effort toward profitable objectives. That's why the basic question can be asked repeatedly – What is the trailer manufacturer trying to make, a travel vehicle or a home?

In this connection it should be said that trailer manufacturers seem more aware of the limitations of the trailer than anyone else. This speaks volumes for them. The most experienced and stable producers know that kaleidoscopic growth has its bad side, and they put a premium on alertness to change. Perhaps that is why well-laid avenues of retreat play a part in programs and why many are loath to plunge into heavy capital outlays. This caution, coupled with aggressive engineering, stamps planning in 1937.

Roger Babson has stirred the country with a prediction that half our population will come to live in trailers, but few trailer manufacturers agree with him. This seems to prove that seers are innocuous, and a few forecasts will be in order.

Trailer design has reached its present stage of wholesome appearance with very little engineering work as one is accustomed to think of it in the automobile industry. From now on such work must and will play a dominant role. If developments don't issue from the manufacturers, they'll come from the purveyors of parts and supplies. Among other things, there will be much more study of trailer performance in relation to the towing vehicle, which in turn will lead to design modification.

There are grounds for believing that emphasis upon the large-size, luxuriously appointed trailer will delimit the market and direct attention to rental rather than ownership, and that present products are not well designed for the mass market, although they might be if prices were lowered.

If the aim of manufacturers is to produce satisfactory year-around homes, ultimate design may be wholly different from

(Continued on page 56)

Selections of Oils for High-Output Aircraft Engines

By A. L. Beall
Research Engineer, Wright Aeronautical Corp.

THIS paper describes the more conventional methods of selecting an oil for use in high-output aircraft engines. It points out the weaknesses of each and justifies the selection of the engine test at high output as the most reliable criterion.

The necessity for oils of better lubricating quality is established based on experience with high-output engines.

A full-scale engine test of oils is urged not only as a basis for selection of an oil that will permit operation of the engine at high output but for another and equally important reason. It is equally important to determine that the oil selected will not be responsible for high maintenance costs and early and frequent replacement of parts.

The paper endeavors to show that carefully conducted engine tests provide information from which oils can be selected resulting in distinct operating economies and probably improved reliability of operation.

THE number of practical methods for selecting an oil for use in high-output aircraft engines may, for practical purposes, be reduced to three, namely:

(1) Accept the selection of the oil refiner.

(2) Prepare laboratory test specifications which the oil must meet.

(3) Run full-scale engine tests as a check on (1) and (2).

The problem has not always been as complicated as it is today. Time was when the selection was practically confined to one oil – castor oil. Whether the limitations of castor oil as a lubricant for consistent and regular operation or the economic pressure of the country's large supply of mineral oil had the greatest weight in the shift to mineral oil, it is nevertheless a fact that the shift was complete, and almost no castor oil is used in this country today.

With the advent of mineral oil and competition among refiners, physical test specifications became the obvious basis of comparison, particularly where successful operating experience was not available as a recommendation.

Selection by the Refiner

If the selection of an oil for a high-output aircraft engine is left to the oil refiner, some limitations are put upon the possibility of getting the most suitable oil.

Leaving the choice to the oil refiner may repose too much confidence in a very limited experience. Lacking very complete experience with modern aircraft engines in the direct comparison of possible oils, it is altogether unfair to the refiner to expect him to demonstrate a talent in extrapolation almost amounting to clairvoyance.

First, the refiner has certain crudes or a certain crude to which he is partial through ownership or with which he has had the most experience in the production of lubricating oil. Leaving the choice to the oil refiner may limit the crude source from which the oil is refined.

Second, each refiner has certain processes to which he is partial through investment in the physical equipment for their employment, and with which he has had the most experience. Leaving the choice to the oil refiner may limit the refining of the oil to a method most suitable for lubricants for other than aircraft-engine lubrication.

Third, the refiner's experience in other fields may be extensive but, unless he has closely followed current aircraft-engine practice and found out what the engine does to his oil, he cannot predict the effect of an increase in engine output.

Selection by Specification

If the criterion for the selection of an oil becomes specifications, it is desirable to consider what each detail of a specification may reflect in engine operation. Possibly specifications should be broken down into classifications according to their known relations to service experience. If so, conventional test requirements would line up about as follows:

Items affecting performance	Items not directly related to performance
Viscosity.	Gravity.
Viscosity index.	Flash point.
Carbon residue.	Fire point.
Oxidation value.	Neutralization number.
Pour point.	Precipitation number.
	Emulsion.

Of the items directly affecting performance in the engine, viscosity is almost the only one with which enough experience has been secured to predict the requirements of a new engine or an established engine under a new set of operating

[This paper was presented at the National Aircraft Production Meeting, Los Angeles, Calif., Oct. 16, 1936.]

conditions. Viscosity index and pour point relate particularly to cold-starting conditions and to oil-temperature-control problems. Some work has been done on automobile engines to relate Conradson-carbon values to actual engine performance.[1] Some work has also been done with automobile engines to relate one oxidation test to engine performance.[2] The author is not aware of any published data which permit the prediction of the significance of given values in these tests for aircraft-engine oils.

Of the items not directly affecting performance, it may be said safely that such specification details are used more for the purpose of identification and relation to previous experience than for any other reason. Given two oils of similar values in all these specification details, it is sometimes safe to assume that they will give similar performance at moderate outputs in the engine.

One question that arises in every operator's mind is how the oil will resist oxidation in the engine. There is no accepted criterion or method of test providing a satisfactory answer to this question. The method used in the work described later seems to provide a fairly definite distinction between oils that oxidize badly in the engine and those that do not. This method, which will be described later, was adopted after others had been rejected, some for the large amount of labor required in their technique and others, for their lack of distinction between oils widely different in engine performance. The method under discussion is unsatisfactory in that it does not distinguish between oils that are highly resistant to oxidation.

Fig. 1 shows a numerical index of general performance quality plotted as abscissa with flash, fire, and A.P.I. gravity as ordinates. As will be seen readily there is little of significant value in the relations shown. Fig. 2 shows a similar plot and a similar lack of relation between performance

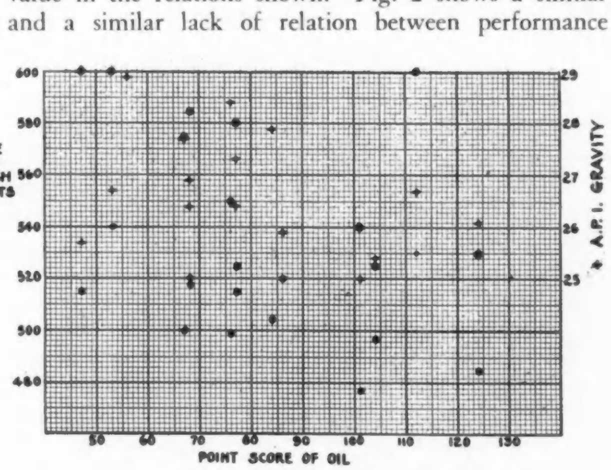


Fig. 1 - Point Score of Oil Vs. Flash and Fire Points, and A.P.I. Gravity

quality as indicated by the numerical index and the neutralization number and emulsion test.

Fig. 3 relates to items affecting performance, namely carbon residue and oxidation value. Some relation normally can be traced between the latter value and engine-performance results, but only in a range greater than that shown as the ordinate of this plot. In this work, few tests have been attempted with oils showing a poor oxidation value because unsatisfactory results invariably were obtained with such oils.

Bearing in mind that the problem is selection of oils for high-output aircraft engines, it is apparent that specifications alone are an unsatisfactory criterion. Assuming some validity for Figs. 1 to 3, it is seen that but one item of the specifications (oxidation value) is at all likely to be reflected in engine performance.

The argument may be raised that a specification may not be broken down successfully and can be considered only as a whole. Fig. 4 shows that there is reason to doubt that our present-day specification requirements insure satisfactory performance in an engine. In this plot the numerical index is

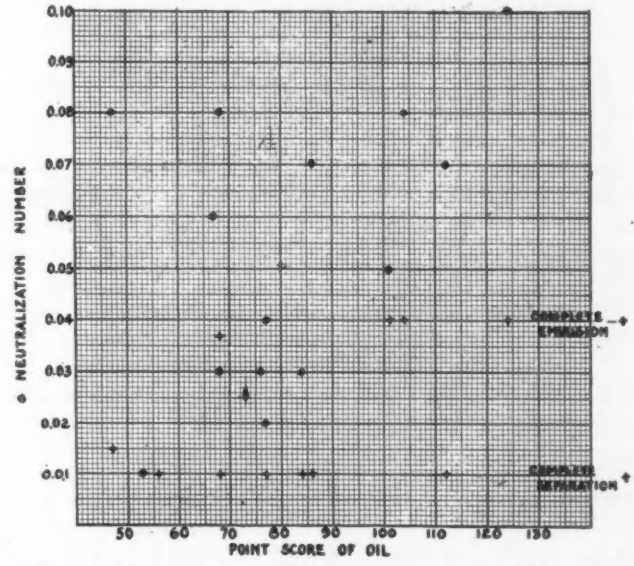


Fig. 2 - Point Score of Oil Vs. Neutralization Number and Emulsion

again used for abscissa, and the ordinates are arbitrary values where each detail of the specification has been given a value of 10. A perfect score in meeting the specification would be 110. None of the oils shown has any values in the specification details below a satisfactory and acceptable level. If the specification cannot correlate always with practice, it surely is a poor basis for selection of oils for more severe service.

There is no intention in this discussion to deprecate the value of specifications or to deny a certain negative dependence upon them. Neither is it at all probable that any of the conventional specification requirements will be discarded in the near future. For the present they will continue to perform the important function of identification. Specifications are the most reliable inexpensive means of determining that successive supplies of a selected oil remain substantially unchanged.

It is also expected that, within the next few years, our present-day specifications will be supplemented by requirements for other tests that will predict the lubricating value of an oil under a variety of conditions of operation. It is sufficient for the present to realize that we are not now in a position to do so.

The most striking thing about a specification for a lubricating oil is that there is nothing in it to tell how well the oil will lubricate. There is, on the other hand, ample evidence of the necessity for a specification measuring such a quality. Poor lubrication makes itself evident where the oil used is deficient in the quality that makes for minimum wear and may be detected readily from the condition of engine parts.

[1] See S.A.E. TRANSACTIONS, June, 1926, Vol. 21, Part II, pp. 150-181; "Influence of Temperature, Fuel, and Oil on Carbon Deposition," by S. P. Marley, C. J. Livingston, and W. G. Gruse.

[2] See S.A.E. TRANSACTIONS, Vol. 29, May, 1934, pp. 167-178; "Causes and Effects of Sludge Formation in Motor Oils," by D. P. Barnard, E. R. Barnard, T. H. Rogers, B. H. Shoemaker, and R. E. Wilkin.

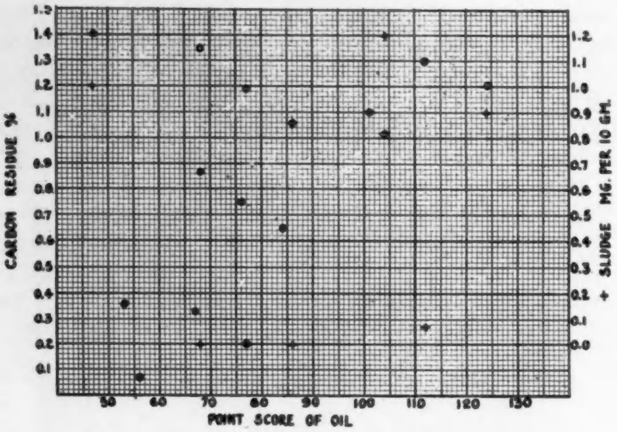


Fig. 3 – Point Score of Oil Vs. Carbon Residue and Sludge

It may be noted in wear of the tapered piston-ring face as described later. In operation at high b.m.e.p. (225 lb. per sq. in. and above) where oil is the only variable between tests, wear may vary appreciably between oils of the same measured viscosity in as little as 5 hr. of operation.

Conventional dive tests with their high-inertia loads may be completed with one oil, whereas the use of another results in bearing failure. All of these wear phenomena are reproducible at will and indicate a serious lack in oil specifications.

Selection by Full-Scale Engine Test

Selection of suitable oils by means of full-scale engine test, although undoubtedly initially more expensive than the methods previously described, has one distinct advantage. It proves the oil and, if carefully completed, rates it comparatively with other oils tested under like conditions. Provided the test is run long enough under the most severe conditions for which the engine is designed to operate continuously, it also establishes a factor of safety most desirable at any time that single-engine operation becomes necessary in a two-engine airplane.

The use of such a test presupposes an ability to evaluate the results with the various oils that complete the test, and to grade them in the order of their performance. Although the difficulties of making reliable distinctions in the interpretation of results have deterred some investigators, it is the purpose of this paper to present a method now in use that has some merit as demonstrated by actual experience.

The limitations of the specification method of selecting oils have long been realized, and time and money have been devoted to the development of laboratory methods of test which tend to increase the value of the oil specification as a means for selecting oils. However, it is evident that, as engines increase in power for a given displacement, the problem of satisfactory lubrication becomes more important and the oil specification is no longer an adequate criterion. As a member of our engineering organization aptly puts it: "Oil is the only material going into engines that is still measured with a yardstick."

With the idea of determining the validity of specifications and laboratory analyses of oils, a program of full-scale engine testing was instituted several years ago. Fairly early in this series of tests the necessity became evident for a uniform method of determining what the oil did to the engine and what the engine did to the oil. The method then developed has been employed since with minor modifications, and now has a background of some 3000 hr. of full-scale engine testing on 35 different oils. Oils for high-output engines are now approved for use only after completing successfully a prescribed full-scale engine test. With the advent of engines with take-off power in excess of 0.5 hp. per cu. in. of displacement, it became definitely evident that neither oil refiners nor specifications were reliable guides in the selection of oils suitable for such engines.

Preliminary Investigation

Some evidence that the oil is superior, based on experimental data and a complete laboratory analysis, must be submitted prior to the test. If upon examination it reveals merit, it is submitted to preliminary tests which, experience has indicated, are at least rough indications of how the oil may be expected to perform in the engine with respect to oxidation (sludge formation) and wear of parts.

The first test is the W.A.C. oxidation test, the apparatus for which is illustrated schematically in Fig. 5. In the aluminum dish shown, a 3.5-cc. sample of oil is heated to 550 deg.

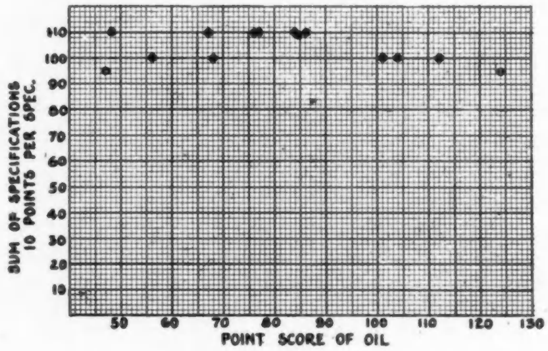


Fig. 4 – Point Scale of Oil Vs. Sum of Specifications

fahr. At the end of 30 min. an additional 3.5 cc. are added while the temperature is maintained constant. The test is carried on for 5 hr. with additions of oil at 30-min. intervals until 35 cc. of oil have been put in the dish, and the last sample exposed to the heat for 30 min. At the end of this time a sample is removed from the body of the oil, care being taken to avoid that part which is baked on the dish. This sample is filtered to determine the naphtha insolubles and the naphtha insolubles that are soluble in chloroform. The results for each, described as sludge and asphaltenes respectively, are reported in milligrams per ten grams. The apparatus and method are described more fully in Appendix I.

In the second preliminary test, the oil is run in the W.A.C. bearing-test rig shown in Fig. 6. This device determines the pressure at which the oil film is unable to separate the friction surfaces. The bearing used is of a conventional hard bronze and supports a hardened steel journal rotating at 1750 r.p.m. Oil is supplied at a uniform pressure of 65 lb. per sq. in. at 45 deg. ahead of the loaded zone of the bearing. The end leakage from the bearing is maintained at a definite quantity for each increment of load by controlling the temperature at which the oil enters the bearing. This arrangement compensates for small differences in oil viscosity and also small differences in change of oil viscosity with temperature. A new bushing very carefully bored to size and with smooth finish is used for each test. A comparison is made at frequent intervals with a reference oil to insure that the apparatus and test conditions are maintained uniform.

Tests are reproducible within ±3 per cent as indicated by the averages of a large number of tests. The apparatus and method are described in Appendix II.

Satisfactory performance in the bearing-test rig for an oil showing good resistance to oxidation and otherwise meeting specifications warrants proceeding with the full-scale engine test.

Full-Scale Engine Test

It is hardly to be expected that all oils offered for the purpose can be subjected to this test which is time-consuming and expensive. Partly as a deterrent to the casual submission of an oil for test and as assurance that the interest in the oil is genuine, the oil refiner or organization submitting the oil for engine test is required to bear part of the expense of testing.

The full-scale engine test usually is conducted in conjunction with tests to evaluate some factor or factors in engine design or material or both. Provided the severity of engine-test conditions is equivalent to a minimum requirement, operation may be under one given set of conditions for 50 hr. or alternated for shorter periods of low and high output to complete 50 hr. of testing at a minimum of 0.40 hp. per cu. in. of displacement. Frequently test routines as prescribed by the military services are employed.

The mechanics of the test are simple. With the engine mounted on the test stand and the system filled with oil, the level of the oil tank is adjusted to a selected value, usually 100 lb. At the end of each 5 hr. of elapsed time, samples of the oil are withdrawn for analysis from the flowing return line to the stand tank. Immediately after the samples are taken, fresh oil is added to adjust the tank level to that of the initial supply and, except in emergency, fresh oil is added at no other time.

Usually at the completion of 50 hr. of testing at the prescribed output, the engine is torn down for examination and measurements for wear. Occasionally the engine is run for a longer period at a lower output after the prescribed 50 hr. are completed, and the examination is deferred until such running is completed. In this case samples are taken at 15 hr. intervals, but are not included in the used oil reserved for evaluation of results.

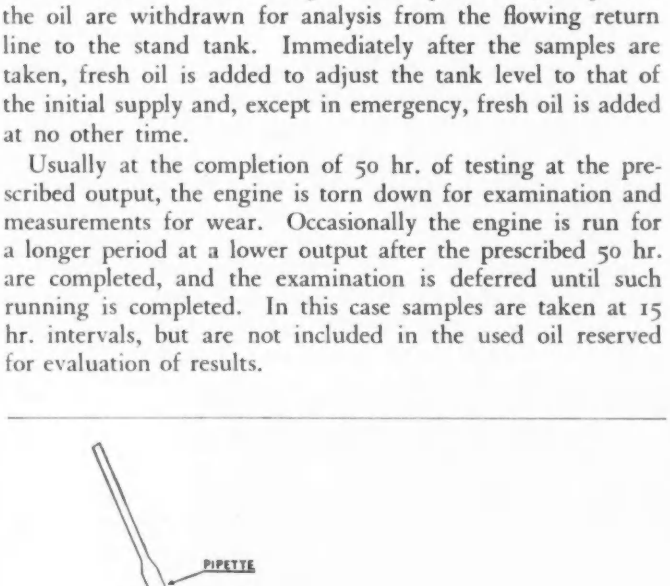


Fig. 5 – Apparatus for W.A.C. Oxidation Test

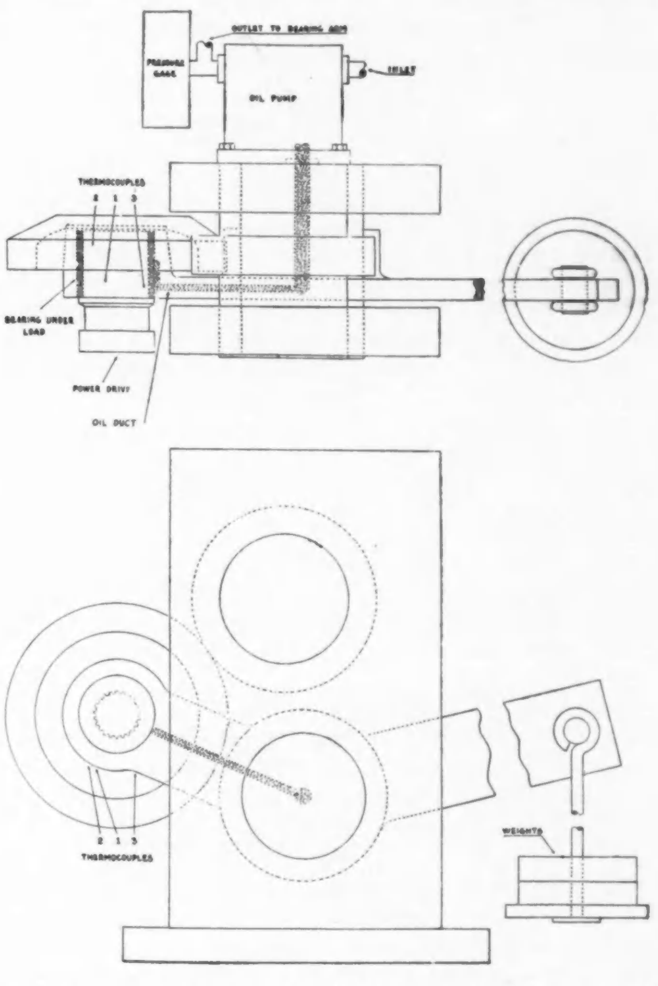


Fig. 6 – W.A.C. Bearing-Test Rig

Engine Inspection

As it is disassembled, the engine is inspected carefully in detail for the wear of parts; carbon, gum, and sludge accumulations; and general cleanliness. The tapered face of the compression rings, Fig. 7, offers a rapid and quite accurate gage of wear as compared with bearings or cylinder barrels and thus permits the rating of oils that prevent any measurable wear in much of the engine in the 50-hr. running time. Carbon in ring grooves, sludge or gum in piston reliefs, as shown in Fig. 8, are noted. The accumulation under the piston head, varnish-like coatings on the connecting rods, appearance and wear of reduction gears and bushings, sludge in the crankcase and in the cavity in the crankshaft, also are recorded and, together with significant wear measurements, make up an evaluation of the effects of the oil on the engine. To simplify the recording of the results of the inspection and to reduce the results of the inspection to a single figure for purposes of ready comparison, each section of the engine is given an optimum or par score, and the inspector penalizes this value of the perfect score as he proceeds for each detail which is below an optimum value established. For convenience, the engine is divided into sections such as pistons, piston-rings, and cylinder barrels, crank system, and bushings, and values are determined for each section which, when totalled, represent an arithmetical figure for the engine inspection of which Table 1 is an example. In the first column are

shown the optimum or par values for an inspection and, at the right, are shown the results of an inspection after a test with oil *X*.

Oil Inspection

In the chemical laboratory a complete analysis for purposes of comparison is made of the new oil and of the last sample of used oil taken from the engine at the end of the test. The samples of used oil taken at 5-hr. intervals are mixed with precipitation naphtha and filtered through a crucible after which they are weighed to determine the naphtha insolubles; then the residue is filtered with chloroform and again weighed to determine what amount of the naphtha insoluble is chloroform soluble. The results of the two determinations are reported as sludge and asphaltene contents respectively. The viscosity of the used-oil samples at 210 deg. fahr. and the neutralization values are determined to find the increase in viscosity with use and the increase in acidity with use.

The accumulated sludge and asphaltenes for the 15- and 50-hr. periods of the test are compared with arbitrarily selected optimum or par figures, and the used-oil inspection results are reduced to a single arithmetical figure. The method employed with the used-oil samples as well as the engine inspection is detailed more fully in Appendix III.

Rating of the Results

At the completion of the test the following data are available for the appraisal of the performance of the oil:

(1) The graphic log of test conditions.
(2) The engine-inspection results.
(3) The used-oil results.

Obviously, differences in test conditions will qualify both the condition of the engine after the test and the oil, either favorably or adversely as the severity of the conditions of test is greater or less. For this reason both engine-inspection and used-oil results are qualified in equations worked out as a result of experience which take into account the horsepower per cubic inch of displacement, the temperature at which the oil is introduced into the engine, and the oil-temperature rise through the engine.

Table 1 – Example of Engine-Inspection Log Sheet

	Optimum or Par Values	Engine Inspection, Oil *X*
Pistons, wear and appearance	5	4
Piston-pin bosses, wear	1	1
Piston thrust surface, appearance	4	3
Piston total	10	8
Piston-rings, wear	20	14
Piston-rings, stuck	5	5
Piston-rings, feather	5	3
Piston-rings, total	30	22
Cylinder, wear and appearance	10	10
Piston-pin, wear	1	1
Link-pin, wear and appearance	4	3
Link-pin bushings, wear and appearance	1	1
Piston-pin eye, wear and appearance	1	1
Master-rod bearing, wear and appearance	14	12
Master-rod journal, wear	8	7
Spider bushings, wear and appearance	3	2
Crank system and bushings, total	32	27
Crankcase, general cleanliness	6	5
Crankcase, sludge	5	4
Master-rod journal cavity	2	1
Filter	5	4
Cleanliness and sludge, total	18	14
Total engine-inspection score	100	81

As being the more significant and reliable criterion of oil performance, the engine inspection is given twice the weight that is alloted to the used-oil analysis results. This is an arbitrary selection and is open to criticism on this ground.

When the qualifying elements of the test conditions have been applied to the results, the several values are reduced to a single figure described as the point score for the oil. This is the index used in the plots of Figs. 1, 2, and 3 as abscissae. Complete details of the method of rating the results of the test are given in Appendix III.

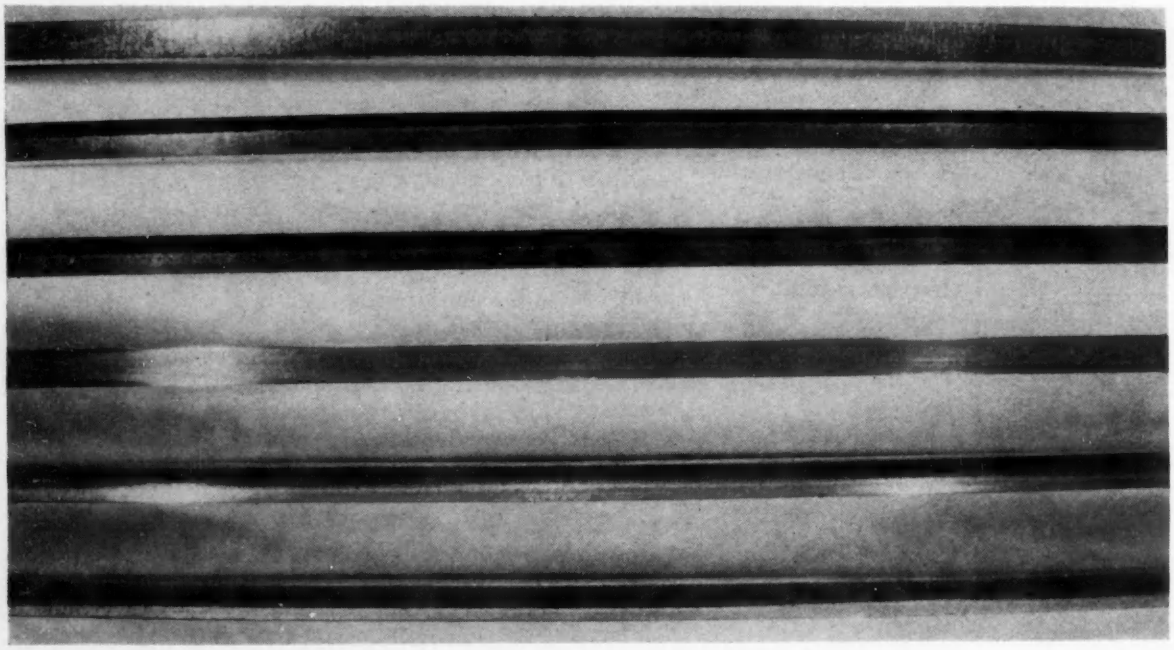


Fig. 7 – Tapered Face of Compression Rings Used as Gage of Wear

Fig. 8 – Example of Carbon in Ring-Grooves and Sludge on Piston Reliefs

It is appreciated that the validity of a chosen criterion for oil selection is open to question unless the experimental data from other methods of selection are compared with it. Unfortunately, the experimental data in this type of experiment are expensive to secure and no single organization can knowingly risk a series of engine failures for the sake of academic interest.

Some correlation between the described method of oil selection and airline operation is available to substantiate the validity of the method. Favorable results in the engine test have been reflected in good results in airline operation. Unfavorable results in the engine test to the point of actual failure in the test have been reflected in airline operation in high mortality of parts, particularly bearings and pistons. It is encouraging to note that a few airline operators have recognized these circumstances and now utilize only such oils as have demonstrated their ability to minimize such expensive results of faulty lubrication.

There is no question in the mind of anyone interested in aircraft engines that better lubricating oils are desirable. The industry is indebted to the oil refiners who have improved and are continuing to improve their oils in an endeavor to keep pace with engine development. Fig. 9 is shown to illustrate that some progress is being made. The method of evolving a point score is designed to compensate for the differences in test conditions used in the various years shown so that the several points on the curve are roughly comparable.

Although the method described is fully appreciated to be far from ideal, it is supported by a large amount of practical experience employing it, and it does offer a basis for rational comparison of oils and a means of evaluating improvements in them. It is offered with the hope that it may help to accelerate the development of further improvements in oil-testing technique, especially in regard to the introduction of laboratory methods having improved correlation with service experience.

The cooperation of agencies equipped to conduct tests on full-scale engines of high output is hoped for as it is believed that tests need not be conducted on one type or make of engine, or by but one laboratory.

Pending the development of satisfactory bench laboratory tests that will reflect full-scale-engine performance characteristics, a method of the type described seems essential for the selection of oils for high-output aircraft engines.

Appendix I

Method for Testing Lubricants in the W.A.C. Oxidation Cup

The apparatus for testing sludge and asphaltenes shall consist of an aluminum cup, a source of heat, a fire shield, a thermocouple, and a potentiometer as shown in Fig. 5. The cup shall be supported by its shield on a tripod or ring stand. A suitable source of heat is a Meeker gas burner with the top of the burner ¾ to 1 in. (19.1 to 25.4 mm.) from the bottom of the cup.

The procedure is to bring the temperature of the cup to 600 deg. fahr., and then introduce a quantity of the oil in the cup by means of a preheated pipette which will deliver 3.5 cc. After holding the temperature of the cup at 600 deg. fahr. for 30 min., another similar quantity of oil is added, and so on at intervals of ½ hr. until ten samples in all have been added. During the entire time of running the test, the potentiometer temperature shall be maintained at 600 deg. fahr. (315 deg. cent.) ± 8 deg. fahr. (4.4 deg. cent.). The lubricant to be tested may be preheated not to exceed 200 deg. fahr. (93 deg. cent.) to facilitate delivery from the pipette. If it is solid above this temperature, the sample must be placed in the cup by means of a spatula in quantities of approximately 3.5 cc. When the oil in the cup has reached a depth sufficient to cover the bulb of a thermometer, a temperature check may be made with a thermometer in the liquid. This temperature will not agree with that of the potentiometer because of heat dissipation but should not be below 550 deg. fahr. (288 deg. cent.).

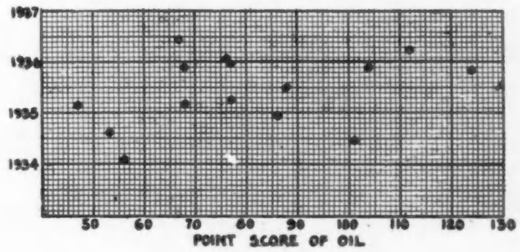


Fig. 9 – Point Score of Oils Vs. Years

The total time of heat shall be 5 hr. As soon as possible after the completion of the run, a sample of approximately 10 gm. of oil is withdrawn by means of a pipette and deposited in a weighed 125-cc. Erlenmeyer flask. This sample is taken from the center of the cup without any stirring of the heated oil which might loosen and detach carbon or coked oil from the sides of the dish. After cooling and accurately weighing the sample in the Erlenmeyer flask, 85 to 95 cc. of A.S.T.M. D91-33 naphtha are poured into the flask which is swirled unstoppered to dissolve the soluble oil. It is then filtered through a dried and weighed RA-84 dense Alundum crucible washing well with naphtha and using customary quantitative analysis precautions. The crucible is heated in a drying oven at 180 to 220 deg. fahr. (83 to 104 deg. cent.) for 1 hr. and afterwards placed in the original desiccator until cool. Residue is then weighed and expressed as mg. of sludge per 10 gm. of sample.

In order to determine asphaltenes, the crucible is next filled half full with chloroform and allowed to stand 1 hr. The chloroform is drawn off by suction, and the residue washed 5 to 8 times with chloroform and then placed in the oven for 1 hr. after which it is placed in the desiccator until cool

and weighed. The amount of chloroform-soluble residue which has been lost as determined from the previous sludge weight is the asphaltenes content and should be expressed in mg. per 10 gm. of sample.

Appendix II

Method of Testing Lubricating Oil in the W.A.C. Bearing Rig

2 gal. of the oil to be tested are placed in the tank and the electric-heating element turned on to bring the temperature to 150 deg. fahr. After the bushing has been diamond-bored to 0.004 in. diametrical clearance on the journal, the arm is installed on the machine and the bearing given a run-in of 1½ hr. with 35 lb. load on the arm or 381 lb. on the bearing. During the run-in, the tank temperature is regulated to give an oil flow through the bearing clearance of 0.38 lb. per min.

Upon starting the test after this preliminary procedure, temperature readings are recorded of the three thermocouple connections near the bearing and the oil tank as well as oil pressure and oil-flow readings. See Fig. 6. An additional 5-lb. weight is added to the 35 lb. already on the arm when the test proper began and, when the bearing temperatures are at equilibrium, the readings are recorded and the oil flow determined. The test proceeds in this manner with weights added in increments of 5 lb., each weight being added only after the temperature rise caused by the preceding weight has reached equilibrium and the oil flow after equilibrium has been recorded.

The oil-flow regulation is of considerable importance in this test and is controlled by tank temperature so that the increase of flow as weights are added follows as closely as possible the slope of the line plotted from these readings: 35 lb. = 0.38 lb. per min., and 160 lb. = 0.90 lb. per min.

The end point of the oil and conclusion of the test is reached when the temperature rise upon the addition of any one 5-lb. weight is rapid and does not return to equilibrium. The rise is quite definite, and the weight pressure is immediately relieved before seizure occurs.

Data obtained in this test are plotted in the form of a curve for comparison with a reference oil run in the same manner.

Appendix III

50-Hr. Endurance Test – Determining the Point Score

(1) This method shall apply to evaluating a lubricating oil after a full-scale engine test.

(2) *Sampling.* – A pint of sample in a quart jar or can together with a 2-oz. bottle (full) shall be taken at 5-hr. intervals during the test. A quart sample of new oil also should be taken for analysis. The 2-oz. sample is to be used for sludge and asphaltene determinations, the pint sample for viscosity and neutralization determinations and, when analyzing, all samples must be stirred well in their containers at 180 deg. fahr. to insure a homogeneous content.

(3) *Used-oil evaluation.* – (a) Sludge and asphaltene values. When a normal sludge value is expected, 10 gm. of sample are deposited in a 200-cc. Erlenmeyer flask and swirled with 75 cc. of solvent naphtha (A.S.T.M. D91-33) to dissolve the oil. After settling for 1 hr., the sample is filtered through a weighed Alundum crucible (RA-84 dense) washing with 60 cc. of naphtha. The crucible is heated in a drying oven at 220 deg. fahr. for 1 hr., placed in a desiccator to cool and weighed. The residue weight is expressed as mg. of sludge per 10 gm. of sample. When abnormally high values of sludge are expected, it is desirable to decrease the amount of original sample accordingly in order to facilitate filtering.

In order to determine the asphaltene, the crucible is next filled half full with chloroform and allowed to stand for 1 hr. The chloroform is drawn off by suction, and the residue washed 8 to 10 times with chloroform. The crucible is then dried in the oven, cooled in the desiccator, and weighed. The amount of chloroform-soluble residue which has been lost as determined from the previous sludge weight, is the asphaltene content and should be expressed in mg. per 10 gm. of sample. In cases where the sludge and asphaltene deposit in the crucible is excessive, it may be necessary to decant the chloroform several times and allow a longer time for soaking before applying the suction.

The sludge and asphaltene accumulations taken at 5-hr. intervals are totaled in two groups:

Group I is the sum of results expressed in mg. from the first three samples or after 15 hr. of running.

Group II is the sum of results expressed in mg. from all 10 samples or after 50 hr. of running.

Calculation:

$$\frac{100}{\left(\dfrac{\text{Sludge Total Group I}}{62}\right)} = \text{Sludge value, Group I}$$

$$\frac{100}{\left(\dfrac{\text{Asphaltene Total Group I}}{20}\right)} = \text{Asphaltene value, Group I}$$

$$\frac{\text{Sum}}{2} = \text{Sludge and asphaltene averaged value for Group I}$$

$$\frac{100}{\left(\dfrac{\text{Sludge Total Group II}}{305}\right)} = \text{Sludge value, Group II}$$

$$\frac{100}{\left(\dfrac{\text{Asphaltenes Total Group II}}{75}\right)} = \text{Asphaltene value, Group II}$$

$$\frac{\text{Sum}}{2} = \text{Sludge and asphaltene averaged value for Group II}$$

(Averaged value Group I + Averaged value Group II) ÷ 2 = Used oil sludge and asphaltene value.

In the absence of samples up to 50 hr., the sludge and asphaltene averaged value for Group I may be considered as used oil sludge and asphaltene value.

(b) Viscosity value. The test for viscosity is made with a Saybolt Universal Viscosimeter as described in A.S.T.M. Method D88-33. Deduct one point from the oil score for each 5 sec. increase in viscosity at 210 deg. fahr. on the 50-hr. sample above the first 10 sec. increase from the value for new oil.

(c) Neutralization number. The test for neutralization number is made in accordance with A.S.T.M. Method D188-27T. Deduct one point from the oil score for each 0.10 increase in neutralization number above 0.10 on the 50-hr. sample.

In the absence of samples up to 50 hr., the deductions in (b) and (c) are made by the results of viscosity and neutralization on the 15-hr. sample.

Calculation:

Used Oil Sludge and Asphaltene Value (a)
Viscosity Deduction (b)
Neutralization Deduction (c)

Remainder = Used-oil score.

(4) *Engine inspection.* – The numbers indicate the score allowed for excellent or perfect condition of parts or as-

semblies shown. Observer will rate each accordingly as a percentage of the perfect score value.

Pistons, wear and appearance	5		
Piston-pin bosses, wear	1		
Piston-thrust surface, appearance	4		
Piston total		10	
Piston-rings, wear	20		
Piston-rings, stuck	5		
Piston-rings, feather	5		
Piston-rings, total		30	
Cylinder wear and appearance		10	
Pistons, rings, and cylinder barrels, total			50
Piston-pin, wear	1		
Link-pin, wear and appearance	4		
Link-pin bushings, wear and appearance	1		
Piston-pin eye, wear and appearance	1		
Master-rod bearing, wear and appearance	14		
Master-rod journal, wear	8		
Spider bushings, wear and appearance	3		
Crank system and bushings, total			32
Crankcase, general cleanliness	6		
Crankcase, sludge	5		
Master-rod journal cavity	2		
Filter	5		
Cleanliness and sludge, total			18
Engine-inspection score			100

(5) *Engine test conditions.* – From the engine log sheets or endurance-test report the following values must be determined:

(a) Hp. per cu. in. displacement.
(b) Average oil-in temperature.
(c) Average oil-temperature rise through engine.

Calculation of Point Score:

Used-oil score × 1 = ———
Engine-inspection score × 2 = ———

$$\frac{\text{Sum ———}}{3} = \text{Net score}$$

$$\left(\left(\frac{\text{Hp./Cu. in.}}{0.46}\right) \times \text{Net Score}\right) - 14 = \text{———}$$

$$\text{Net score} + \left(\frac{\text{Average oil-in temperature, deg. fahr.}}{185} \times 10\right) = \text{———}$$

$$\text{Net score} + \left(\frac{\text{Average oil-temperature rise, deg. fahr.}}{75} \times 4\right) = \text{———}$$

$$\frac{\text{Sum of 3 ———}}{3} = \text{Point score of oil}$$

Example:

Laboratory Analysis	15 Hr.	50 Hr.
Sludge value	59	294
Asphaltene value	18	49
Viscosity increase		6 sec.
Neutralization-number increase		0.10

Calculation:

$$\frac{100}{\left(\frac{59}{62}\right)} = 105 \text{ Sludge, 15 hr.}$$

$$\frac{100}{\left(\frac{18}{20}\right)} = \underline{111} \text{ Asphaltenes, 15 hr.}$$

$$\frac{216}{2} = 108 \text{ Sludge and asphaltenes, 15 hr.}$$

$$\frac{100}{\left(\frac{294}{305}\right)} = 104 \text{ Sludge, 50 hr.}$$

$$\frac{100}{\left(\frac{49}{75}\right)} = \underline{153} \text{ Asphaltenes, 50 hr.}$$

$$\frac{257}{2} = 128 \text{ Sludge and asphaltenes, 50 hr.}$$

Sludge and asphaltene, 15 hr. = 108
Sludge and asphaltene, 50 hr. = 128

$$\frac{236}{2} = \textbf{118 Sludge and asphaltene value}$$

Viscosity deduction	1	
Neutralization number deduction	1	
Total deduction	2	−2
		116 Used-oil results

Engine-inspection score .... 81 × 2 = 162
Used-oil results .... 116 × 1 = 116

$$\frac{278}{3} = 93 \text{ net score}$$

$$\left(\left(\frac{0.41 \text{ (Hp. per cu. in.)}}{0.46}\right) \times 93\right) - 14 = 69$$

$$93 + \left(\left(\frac{185 \text{ (oil-in temperature)}}{185}\right) \times 10\right) = 103$$

$$93 + \left(\left(\frac{30 \text{ (oil-temperature rise)}}{75}\right) \times 4\right) = \frac{94.6}{266.6}$$

266.6 ÷ 3 = 88.8, Point score of oil qualified by operating conditions.

Discussion

Suggests One-Cylinder Engine Tests

– C. F. Becker
Associated Oil Co.

THE paper presented by Mr. Beall should be interesting to both the petroleum and aircraft industries. In the closing paragraphs of the paper an appeal was made to develop oil-testing technique that would improve correlation with aircraft-engine service experience. In the light of this plea the following discussion may be of interest:

For some time past large users of motor oils have selected their lubricants strictly on the basis of certain well-established laboratory tests, whereas a few large users of lubricating oils have utilized specifications as a preliminary indicator, combined with other special tests which tended to correlate more closely with the equipment in question. In the latter instance the U. S. Navy has for many years utilized the Navy Endurance Friction-Testing Machine for numerically evaluating the performance requirements of lubricating oils for Naval service. Although this test was intended to permit evaluation of oils for a wide variety of uses, it is possible that, for such specific services as high-performance aircraft-engine lubricants, it may need modification.

In view of new processes being used and developed by the oil industry, together with a rather extensive use of synthetic dopes or addition compounds to lubricating oils, it is reasonable to expect that many of the old-established laboratory tests may not provide adequate evaluation of lubricating-oil performance, particularly for certain types of service, such as high-performance aircraft engines. It therefore appears that new test methods may have to be developed. Since no laboratory test is of value unless it indicates service-performance characteristics, obviously in the case of aircraft-engine lubricants a great deal of correlation work will be required. Along with this correlation work will be the task of ascertaining the individual desirable characteristics of an oil for aircraft engines. To obtain an overall picture of lubricating-oil performance in aircraft engines, it may be necessary to ascertain not only the characteristics of the oil before and after service in an engine, but also to determine what effect it has had on the various internal parts of the engine. Incidentally this point was mentioned by the author. In the light of the foregoing it appears that a number of new-type laboratory tests or modifications of present laboratory tests need to be developed, together with some form of simplified and inexpensive engine test. Although full-scale engine tests may hold the final answer to oil performance, the time and expense involved dictate that this other phase of testing be given serious consideration to overcome objections previously cited.

The general type of tests that may be utilized or developed as an indicator of lubricating-oil performance in aircraft engines are listed as follows:

(1) *Viscosity, viscosity index, pour point.* – These already established

laboratory tests may be utilized to determine the low-temperature starting characteristics of aircraft lubricants.

(2) *Volatility tests.* – Flash point is a rough indicator of volatility and may be supplemented by a vacuum distillation test to ascertain the viscosity-volatility relationship, which would allow conclusions as to consumption characteristics.

(3) *Stability test.* – A stability test based on the combined action of heat and air upon the oil. Certain metals, preferably iron and copper, should be considered as accelerating catalysts in such a test. As a criterion of quality, the increase in viscosity and the formation of sludge (precipitation number) due to oxidation and polymerization might be used.

(4) *Corrosion tests.* – A corrosion test to indicate corrosive characteristics of lubricants on bearing metals.

(5) *Film strength and metal affinity.* – A test to determine film strength of lubricants, utilizing bronze specimens of the same composition as the bearing metals, conducted on some form of extreme-pressure machine. Also with steel specimens of proper hardness and definite surface structure.

(6) *Engine tests.* – The use of a one-cylinder engine, either utilizing the regular cylinder and piston assembly of a production aircraft engine, or a one-cylinder jacketed engine utilizing a cooling medium which maintains a temperature range as prevailing in an air-cooled cylinder. It is possible that a form of engine as mentioned may permit correlation with multicylinder full-scale engines and thus provide an inexpensive working tool for anyone interested. Single-cylinder units undoubtedly could be constructed precisely to permit operation by anyone interested, and permit measurements of piston-ring wear, cylinder wear, ring sticking, formation of carbon, gums, and resins.

It is felt that the combined efforts of members of the oil and aircraft industry, and members of the Fuels and Lubricants Committee of the Society may lead ultimately to the proper testing method for valuating performance of aircraft lubricants.

Believes Author's Method Only Sure Way

–C. M. Larson
Sinclair Refining Co.

WITH the introduction of solvent-extraction methods of refining and with the "dopes" for making high-viscosity-index oils, specifications dealing solely with the history as to the crude used and method of refining are no longer sufficient to insure adequate aircraft-engine lubrication.

A. L. Beall's method of approval and selection by full-scale aircraft-engine testing is the only sure way of assuring the airline operator a definite product which will give the maximum service-hours between complete overhauls. It also guards against stuck rings and increased barrel wear, even though the engine is forced at take-off or in making schedule time against adverse head winds. Such maximum-load conditions are very severe on the aircraft-engine lubricating oil. Only by a 50-hr. or more engine endurance test can the refiner be sure that his oil is refined properly and that it has proper oiliness.

Mr. Beall is to be congratulated for the completeness of his approach and the courage of putting such a method of selection into actual use. It is unfortunate that the plan is expensive, but lubrication of high-output aircraft engines is difficult and the hazards to life are so dependent on a sufficient factor of safety that it is unwise to depend on specifications alone. The best-known specifications can be met with oils that cause engine failures in less than 50 flight-hr. of service.

Outlines Research Program on Bench Laboratory Tests

–Lt. Charles F. Coe
U. S. Fleet Aircraft, San Diego, Calif.

I CONCUR entirely with Mr. Beall in that current specifications for aircraft lubricating oils are inadequate and that the only sure method for selecting oils at present available is carefully controlled full-scale engine tests.

The obvious solution, of course, is the development of satisfactory bench laboratory tests that will predict with reasonable accuracy the full-scale aircraft-engine performance characteristics of oils. This task has been assumed by the N. A. C. A. Subcommittee for Aircraft Fuels and Lubricants, and work is now under way at the Bureau of Standards under the able direction of Dr. O. C. Bridgeman of that Bureau. This N. A. C. A. project is financed jointly by the Navy Department Bureau of Aeronautics, the U. S. Army Air Corps Materiel Division, the National Bureau of Standards, and the National Advisory Committee for Aeronautics.

As I remember it, the procedure will be about as follows:

Bench laboratory test apparatus for cylinder and ring wear, "oiliness" or coefficient of friction, sludge formation, and acidity increase are being developed. In addition, the effects of oil acidity on aircraft-engine bearing materials will be investigated in an effort to set practical limits on the kind and extent of acidity allowable in use.

The laboratory-apparatus test conditions will be chosen so as to reproduce, as nearly as possible, the results on the oils obtained in a long series of full-scale engine tests conducted under procedure very nearly identical with the test procedure given in Mr. Beall's paper. The first series of full-scale engine tests is believed to be now under way using a twin Wasp Jr. engine. New specially honed cylinders, new rings, and new bearings as necessary, will be used in each run. Careful selection of engine parts for conformance to special close test specifications, and careful control of engine-test conditions will be emphasized. Repeat runs of a reference oil will be made to determine the reproducibility limits of the full-scale engine tests.

It is to be hoped that this research will be successful in providing laboratory bench tests which will predict oil performance in the engine. Such tests will not only permit use of the specification as an adequate criterion in the selection of oils for aircraft engines, thus eliminating expensive full-scale engine tests, but will aid the refiner in developing better oils.

Where Is the Trailer Going?

(Continued from page 47)

anything on the market. It is not certain that housing can be solved by the trailer. The trailer may serve merely as a stimulus to radical departure in building. In the long run it will have to be decided whether or not space limitations are offset by mobility and if some compromise must not be effected. Architects seeking housing solutions have studied the trailer and found it wanting (of course, there are some exceptions). Extreme economy of space imposed by the nature of the trailer does not mean necessarily economy of cost. The contrary may be true. Where land is cheap, over-stuffed cubage is wholly unnecessary and undesirable because, for a given outlay, more livable quarters can be had with orthodox means.

It should be mentioned right here that designs are being pioneered to give more living space. Corwin Willson's plans for a two-story trailer are widely known; some engineers are familiar with William B. Stout's expansible product. The latter conforms to normal trailer dimensions when in motion, but expands to increase floor space and cubage when parked for living. Criticism has been levelled at this type of trailer in the past, because it involved some manual operations to pitch and break camp. It is a nuisance, but nuisances are always relative. The frequency of the setting-up exercises depends wholly on the ratio of travel to occupancy. Hasn't this design merit for persons who profess to be seeking a home? It seems to be a step in the right direction – not for all types of trailers, but for those intended as permanent homes.

In conclusion, it might be to the point to make a few forecasts about this year. I look for an output approximating 75,000 units. That would be a 100 per cent increase over 1936. Estimates run as high as 200,000, but I see no probability of such production. To say that production won't reach great heights isn't pessimistic; the trailer industry will be the sounder for slowing its pace. A further mushrooming of growth would be likely to deplete the ranks of producers and to multiply problems beyond hope of ready solution.

And so, let us keep on asking: What is the trailer today, a transport vehicle or a home?

Spotwelding and Seamwelding the Aluminum Alloys

By G. O. Hoglund
Aluminum Co. of America

THE potential economies that are possible in electric-resistance-welding structural parts made from the aluminum alloys have been realized to a limited extent. Considerable development work already has established the fundamental equipment requisites for making welds, and the characteristics of the various alloys from the standpoint of strength and corrosion resistance of the welds.

Some of the applications from which satisfactory service is being obtained with spotwelded and seamwelded parts include airplane and bus gasoline and water tanks, bridge flooring, cooking utensils, radio-equipment racks – in fact, the process is adaptable to the assembly of any parts with a section thickness of less than 3/16 in. which, in past practice, have been riveted.

Proper equipment is essential to obtain sound, consistent welds in the shop. For general work we have found that a machine with a 42-in. throat that will deliver a current of 42,000 amp. at the tips can be adapted to a varied jobbing production. Pressure is applied pneumatically up to a maximum of 1200 lb. at the tips. Full electronic timing is desirable for spotwelding and is essential for seamwelding. Good spotwelding results also can be obtained with vacuum-tube or mechanically controlled contactors for some classes of work.

The strength of welds in the various aluminum alloys is dependent on the alloy being welded and on the temper and gage of the material. The static shear strength and the resistance to vibration or fatigue loading of spotwelds are comparable to rivets. Salt-spray and atmospheric-corrosion tests have indicated that the corrosion resistance of the welds is substantially as good as the parent material. Complete data on all combinations of gages and alloys have not as yet been collected. Tables and curves on some of the commonly used alloys are shown in the paper.

THE development in modern engineering practice of built-up structures in which the strength is dependent on the form and the use of high-unit-strength materials, has given considerable impetus to the development of economical joining methods for these structures. Because of the stability and high strength-weight ratio inherent in aluminum and its alloys, these materials are playing a prominent part in present-day design.

It is common practice, and in the past it has been almost universal practice, to join aluminum-alloy parts by riveting or bolting. In order to attain maximum strength in the structure full advantage is taken of the high strength obtainable by heat-treating or cold-working these materials. Other methods of joining than riveting have been attempted, particularly fusion welding with the torch or the arc, but the results have not been entirely satisfactory where maximum structural efficiency is required. The thermal effect of the welding heat on the parent material introduces distortion problems that are difficult to handle and partially obliterates the added strength obtained by heat-treating or cold-working.

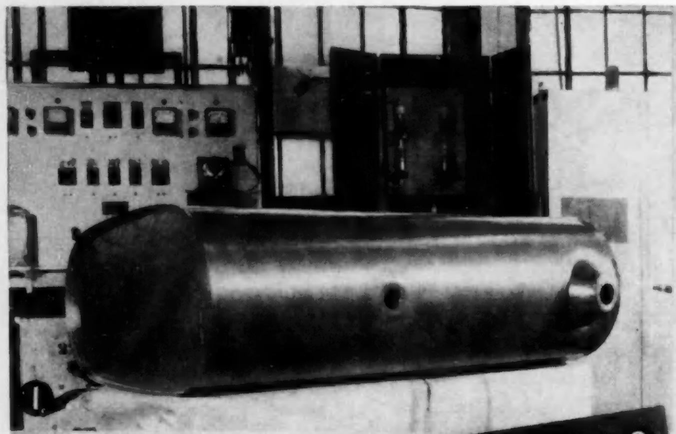
Although the mechanical strength of riveted joints, in general, is satisfactory, considerable effort has been expended to develop a spotwelding technique that can be used on the aluminum alloys in order to obtain the economies that have been experienced with this method on other materials.

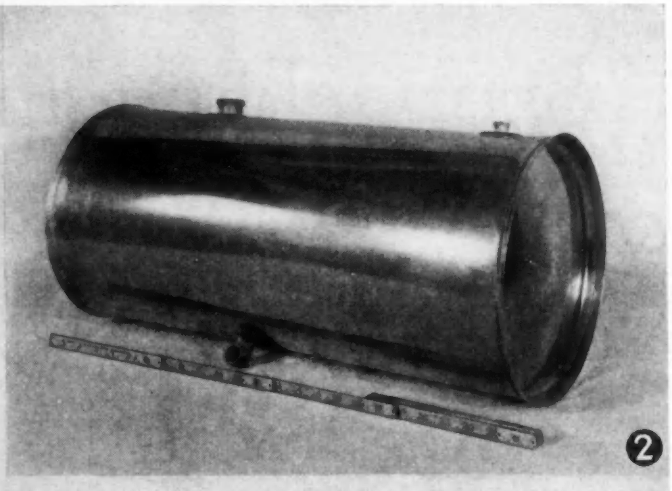
Four operations are involved in driving a rivet: First, the parts are aligned, and the rivet hole located. Second, the hole is drilled. Third, the rivet is inserted and, fourth, the rivet head is formed. A spotweld, on the other hand, requires only two of these operations: first, aligning the parts to locate the weld and, second, making the weld. It follows that, other things being equal, the time required for making the individual welds is less and, consequently, the cost is lower for spotwelded joints.

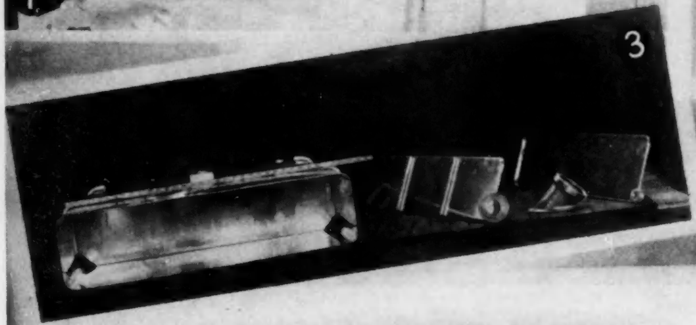
There are other advantages apparent in using spotwelded joints. In the aircraft and marine fields, the smooth outside surface that is obtained with spotwelded joints can be used to lower the drag forces as compared with similar joints made with protruding rivet heads. This factor is sufficiently important to be significant at the high operating speeds now being used. In addition, the problem of preventing leaks around loose rivets in such parts as tanks where gas or liquid tightness is important, should be lessened by the use of spotwelding or seamwelding to make the weld as no piercing of the surface is done in these methods.

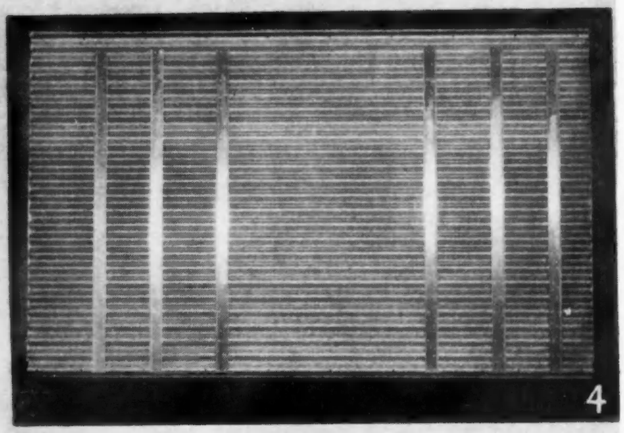
On the basis that the above generalities are facts, intensive development work has been carried out during the past five

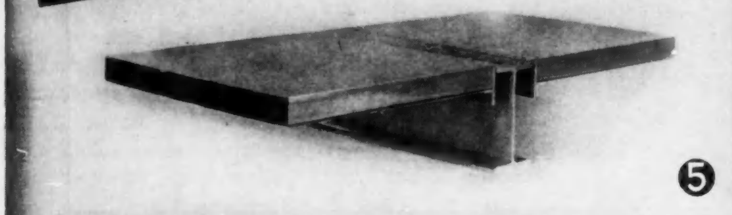
[This paper was presented at the Annual Meeting of the Society, Detroit, Mich., Jan. 14, 1937.]

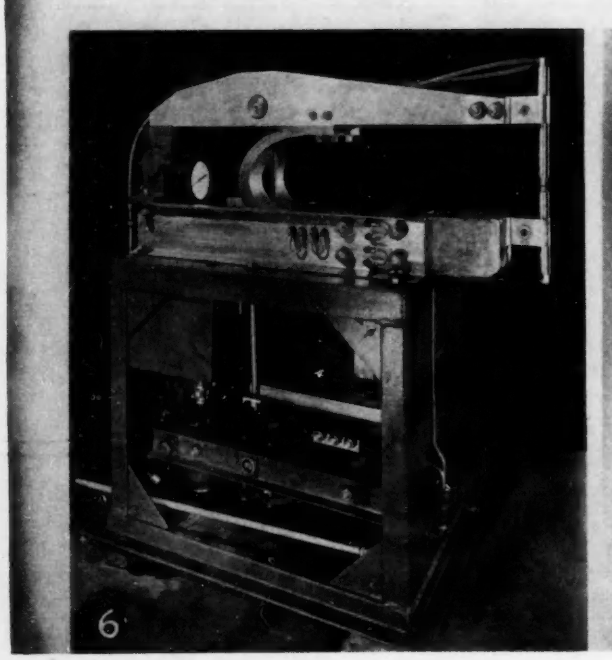












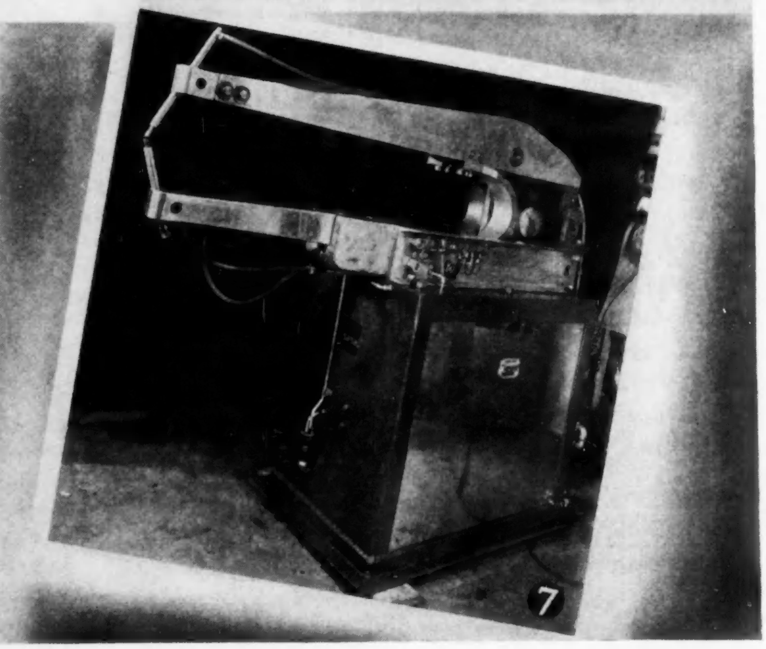


Fig. 1 – Spotwelded and Seamwelded Airplane Gasoline Tank Showing the Smooth Exterior That Can Be Obtained by This Method of Joining – This Tank Contains Five Internal Baffles Spotwelded to the Skin

Fig. 2 – Airplane Water Tank with Seamwelded Heads

Fig. 3 – Constructional Details of Gasoline Tank for Motor Bus with Spotwelded Baffles and Head Stiffeners

Fig. 4 – Corrugated Sheet Bridge-Flooring Section with Spotwelded Stiffeners

Fig. 5 – Use of Spotwelds for Assembling Light-Weight Panels

Fig. 6 – Pneumatically Operated Spotwelder with 36-In. Throat and Capacity of 42,000 Amp.

Fig. 7 – Same Machine as Shown in Fig. 6 but with Longer Arms to Give 48 In. Throat Depth and a Capacity of 34,000 Amp.

years to produce equipment suitable for resistance welding the aluminum alloys and to establish the characteristics of the various alloys from the standpoint of strength and resistance to corrosion of the welds. This paper is concerned mainly in setting down the present status of the art.

The potential economies in resistance welding the aluminum alloys have been realized to a limited extent. A typical example, shown in Fig. 1, is the use of both spotwelding and seamwelding in assembling airplane gasoline tanks. Sufficient time has not elapsed to establish the service life of tanks such as shown in Figs. 1 and 2, but the designs have passed the thorough preliminary tests required on this type of structure. Similar construction has been used for bus tanks as shown in Fig. 3, with capacities up to 85 gal. Several years of satisfactory service on about 3000 tanks of various designs has shown the suitability of spotwelds for this purpose. 700 bridge-flooring panels of the type shown in Fig. 4 with spotwelded channel-attachment pieces and end stiffeners have shown satisfactory service for 3 years. The use of spotwelds for stiffened panel sections is shown in Fig. 5. Although these examples are typical of the type of work being done, they comprise only a small part of the production of resistance-welded aluminum-alloy designs. Other applications include airplane cowling and fittings, cooking utensils, railway-car panels – in fact, the process is adaptable to the assembly of almost any parts with a section thickness less than $\frac{3}{16}$ in. which, in past practice, have been riveted.

Resistance-Welding Equipment

Spotwelding and seamwelding equipment as designed and used for other metals is, in general, not suitable to obtain best results when welding the aluminum alloys. The reason for this unsuitability is apparent when the physical characteristics of the metal are considered. Aluminum and aluminum alloys have comparatively high thermal and electrical conductivity. It follows that the amount of current to make a weld is high compared to that required for other materials, and the time period allowed for the passage of the current must be comparatively short, or undesirable melting and distortion will occur in the parent material near the weld.

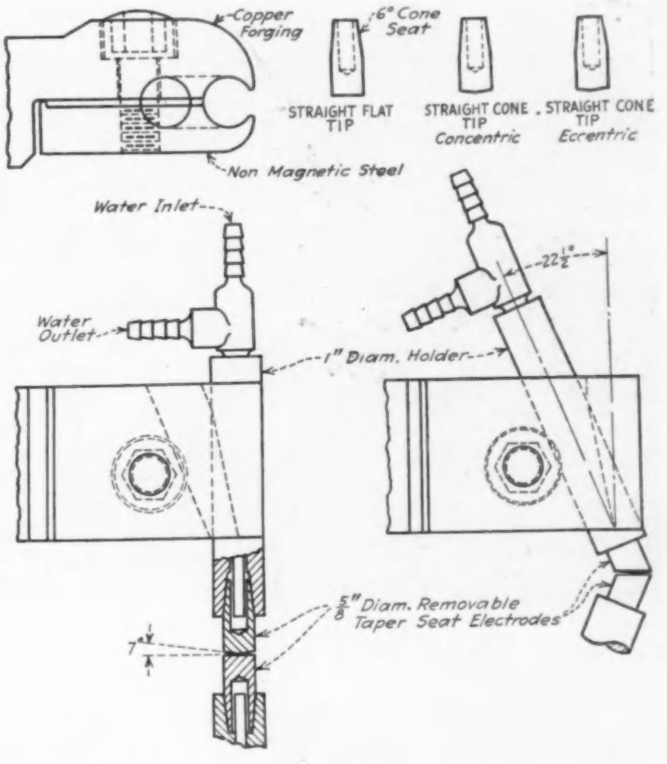


Fig. 9 – Spotwelding Tip Holder and Tip Assembly

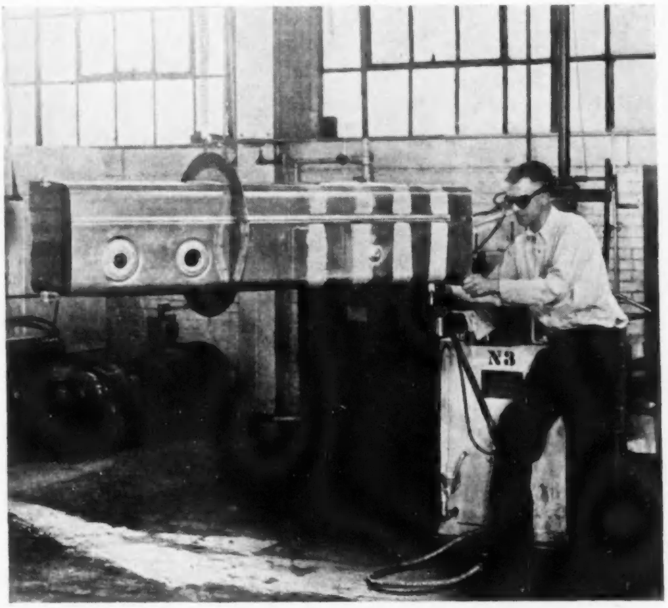


Fig. 8 – Shop Set-Up for Spotwelding Airplane Gasoline-Tank Design – Note Fixture for Holding Tank and Preparation of Surface Prior to Welding

A resistance-welding system consists of a transformer to take the current from the distributional system and change it so that maximum heating effect, or amperage, is available at the weld, a mechanism to apply pressure at the weld and conduct current to the weld, and a means of timing the current to insure accurate control of the heating effect of the current in successive operations.

The design of the transformer is a function of throat depth and the distance between the arms of the machine and the gage of the material that is to be welded. Experience has shown that a machine should deliver at least 24,000 amp. at the tips to weld $\frac{1}{16}$ in. thick material, 33,000 amp. to weld $\frac{1}{8}$ in. thick material, and 42,000 amp. to weld $\frac{3}{16}$ in. thick material. A means of integrating the maximum current to permit welding intermediate thicknesses also is required. An auto-transformer that will control the primary voltage from 20 per cent full voltage to 100 per cent voltage in 25 to 30 steps, will provide adequate control of the current. In this connection it should be noted that the conventional kva. or kw. rating on a machine nameplate is generally not a reliable means of determining the machine capacity. The capacity in amperes at the tips can be determined for various arm positions by simple electrical tests, and a calibration of the equipment is a first essential when starting on an aluminum job.

In connection with the pressure mechanism, it is desirable that the upper or moving head be as light as possible to reduce the inertia loads and to minimize mechanical damage or distortion, particularly in light-gage parts. Pneumatic or hydraulic actuation of the pressure can be regulated accurately and quickly. These methods also provide constant pressure regardless of the distance between the tips prior to making the weld. For many jobs it is desirable that the mechanism

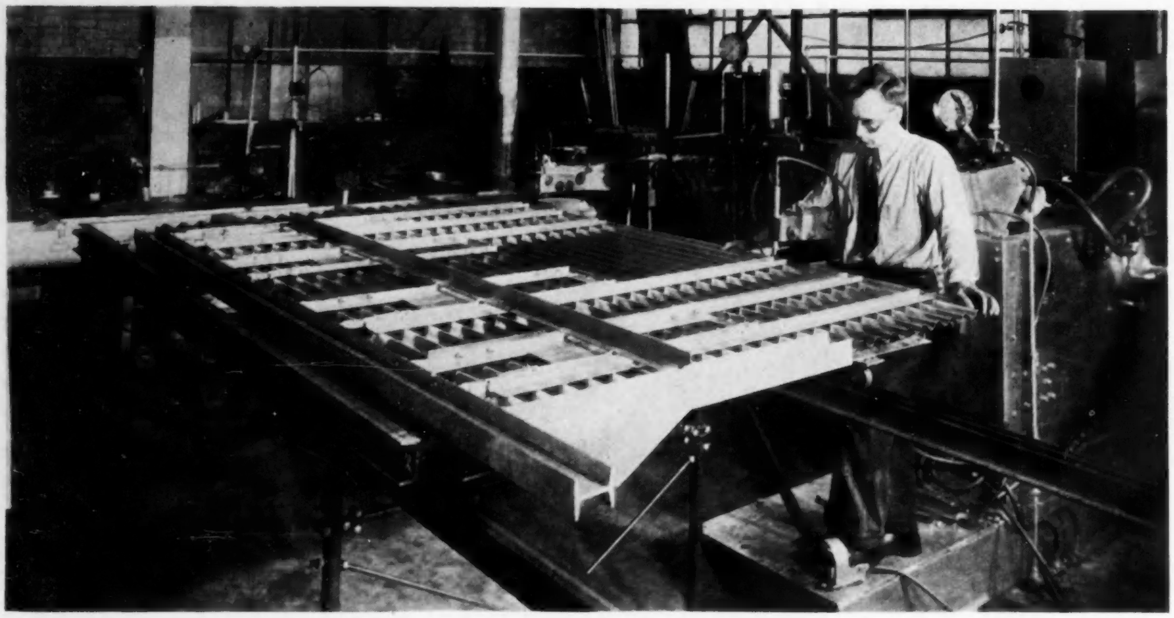


Fig. 10 – Movable Table for Supporting Flat Panels for Spotwelding, and Jig for Spacing Stiffener Channels

be arranged to permit application of the pressure to clamp the parts prior to the application of current.

It is important that proper timing equipment be used to obtain consistent results in either spotwelding or seamwelding the aluminum alloys. This equipment must be such as to insure duplicate shots of power to the work, and manually operated switches, with which the operator can vary the time of the impression of current, are not satisfactory. Best spotwelding results are obtained with full electronic equipment that will time the current synchronously. For welding gages between 0.015 in. and 0.188 in. thick, periods varying from 2 cycles to 25 cycles of the standard 60-cycle current wave are required. Good results also can be obtained on many types of work with the non-synchronous-contactor type timers actuated either mechanically or by vacuum tubes.

When seamwelding, it is essential that full electronic equipment be used. The technique required involves delivery of the current to the work at a duty cycle of less than 30 per cent. Timing cycles of 1 cycle on and 3 off; 1½ on, 4 off; or 2 on and 6 off are typical of the settings used for seamwelding from 0.032-in. to 0.064-in. material. No adequate means other than electronic timing are available for this service.

The design of the machine, throat depth, and so on, are dependent on the class of work to be done. For general purposes, however, the spotwelder shown in Figs. 6 and 7 has been used with good results. This machine is air-operated and arranged so that the arms can be set in any position with the tips either closed on the work or open, to suit the job. A current of 42,000 amp. is obtained at the tips with a throat depth of 38 in. Another set of arms permits increasing the throat depth to 48 in., but the capacity is lowered to 34,000 amp. Machines of this type, or designed on the same principles to suit particular jobs, can be obtained commercially from almost all of the welding-machine manufacturers.

Shop Application of Resistance Welds

Experience has determined certain factors that are of importance in the control of shop operations if full advantage is to be taken of the capabilities of resistance-welding equipment. These factors include preparation of the work, maintenance of electrodes, and checks on the machine set-up; they are described as follows:

Preparation of the work to insure consistent strength of the welds and rapid welding involves proper fitting of the parts and cleaning the surface. It is essential that contact between adjacent parts be obtained in assembly of the parts to be welded. The resistance in the joint, and consequently the strength of the weld, is dependent on the pressure. If a large portion of the pressure between the tips is used to draw the parts together, it follows that the strength of the welds will not be consistent. In addition, improper fitting of the parts will cause distortion in the structure and, in some cases, preloading of the welds.

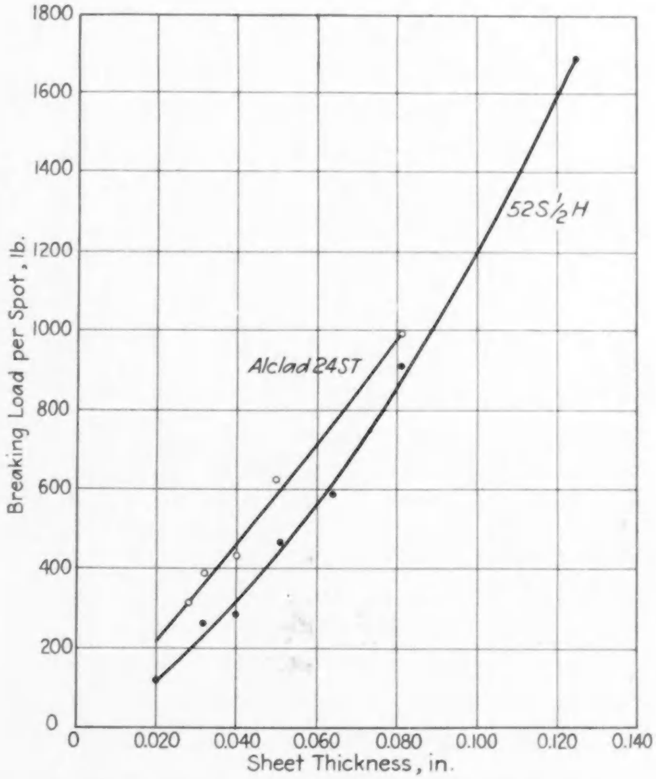


Fig. 11 – Strength of Spotwelds in Alclad 24ST and 52S½H Sheet

All aluminum is covered with an oxide coating that forms in the atmosphere, which coating varies in thickness depending on the fabricating procedure used in making the particular alloy. The electrical resistance of the coating is comparatively high, and the size of the weld is a function of thickness of the coating at the interface between the parts. Also, the presence of a heavy coating on the outside of the parts contacting the tips causes excessive surface heating and alloying of the aluminum with the tip material and, consequently, it causes low tip life. Except on commercially pure aluminum (2S) and on the alloy 3S, where the coating is not sufficiently thick to be harmful, it is desirable to remove the coating prior to welding on all of the aluminum alloys on the surface of the metal contacting the tips. In some cases, particularly the heat-treated alloys where the coating is unusually

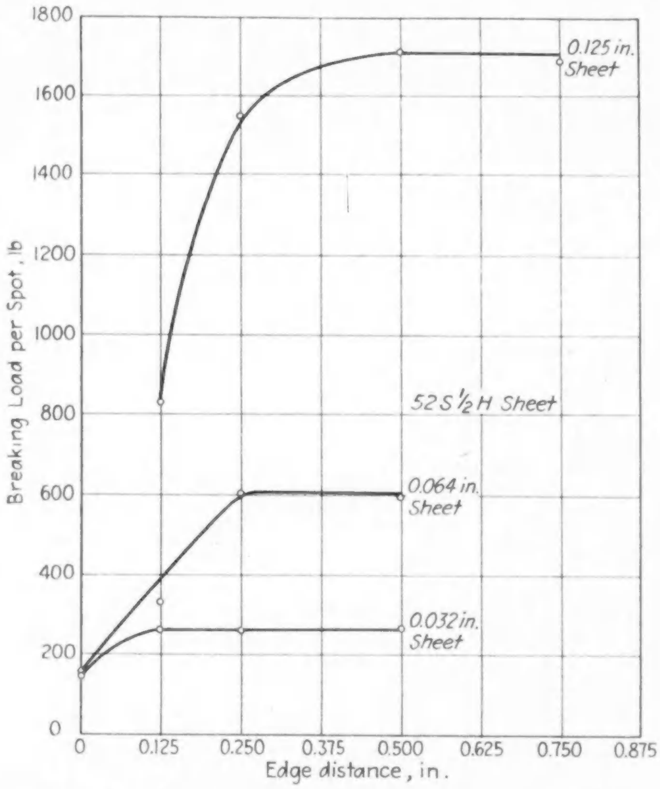


Fig. 12 – The Effect of Edge Distance on the Strength of Spotwelds in 52S½H Sheet

heavy, it also is removed from the contact area between the parts.

Removal of the coating can be accomplished mechanically with an abrasive cloth or by wire-brushing with a fine wire wheel. On large parts removal of the coating can be done more economically with a chemical etch. An etching solution that has been found useful for this purpose is prepared by first dissolving 2.9 lb. of gum tragacanth in 80 lb. of boiling water. Solution of the gum tragacanth can be accelerated by adding 7.1 lb. of denatured alcohol, although this accelerator is not necessary with all grades of gum. The preparation of the etching solution is completed by adding 10 lb. of 30 per cent hydrofluoric acid.

Cleaning is done by painting the area to be welded with the etching solution and then by washing the surface with water after a period of from 15 to 30 sec., depending on the condition of the surface. Although the cleaning usually is done just prior to welding, the surface can be preserved easily

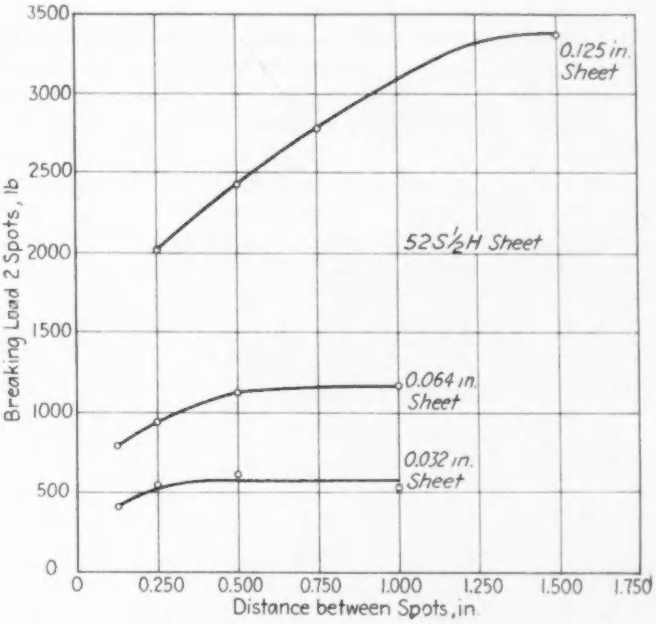


Fig. 13 – The Effect of the Distance Between Spots on the Strength of Spotwelds in 52S½H Sheet

for several days by painting the cleaned areas with a light oil. The use of an etch for cleaning is illustrated in Fig. 8 showing the spotwelding of baffles in an airplane gasoline tank.

Proper design and maintenance of electrodes are essential to obtain consistent spotwelds on aluminum. Variation of the contact area of the electrode tip will change the current and pressure distribution and contribute to inconsistent strength of the welds. The common method of dressing electrodes with a file is entirely unsuitable for spotwelding aluminum. A simple means for maintaining tip contour is shown in Fig. 9. A 165-deg. included angle cone is machined on the tip, and in use no cleaning is done on the tip surface with anything but a very fine grade of abrasive cloth. A tip of this type will make between 250 and 400 spotwelds before re-machining is necessary. Equally good results have been obtained with spherical ends on the tips, but the foregoing procedure was adopted because of the ease of machining the tip contour.

Copper alloys with high electrical conductivity and mechanical strength have proved most satisfactory as tip materials. Various materials have been investigated for this purpose, and no alloy of copper with a conductivity less than 75 per cent of pure copper, has been found suitable. Hard-drawn copper rod will make good spots without excessive alloying or "pick-up" with the aluminum surface, but will anneal and mushroom in production. There are a number of heat-treated copper-alloy materials available that are suitable for this service. Water-cooling to within ⅜ in. of the contact surface of the tips is necessary to insure good tip life.

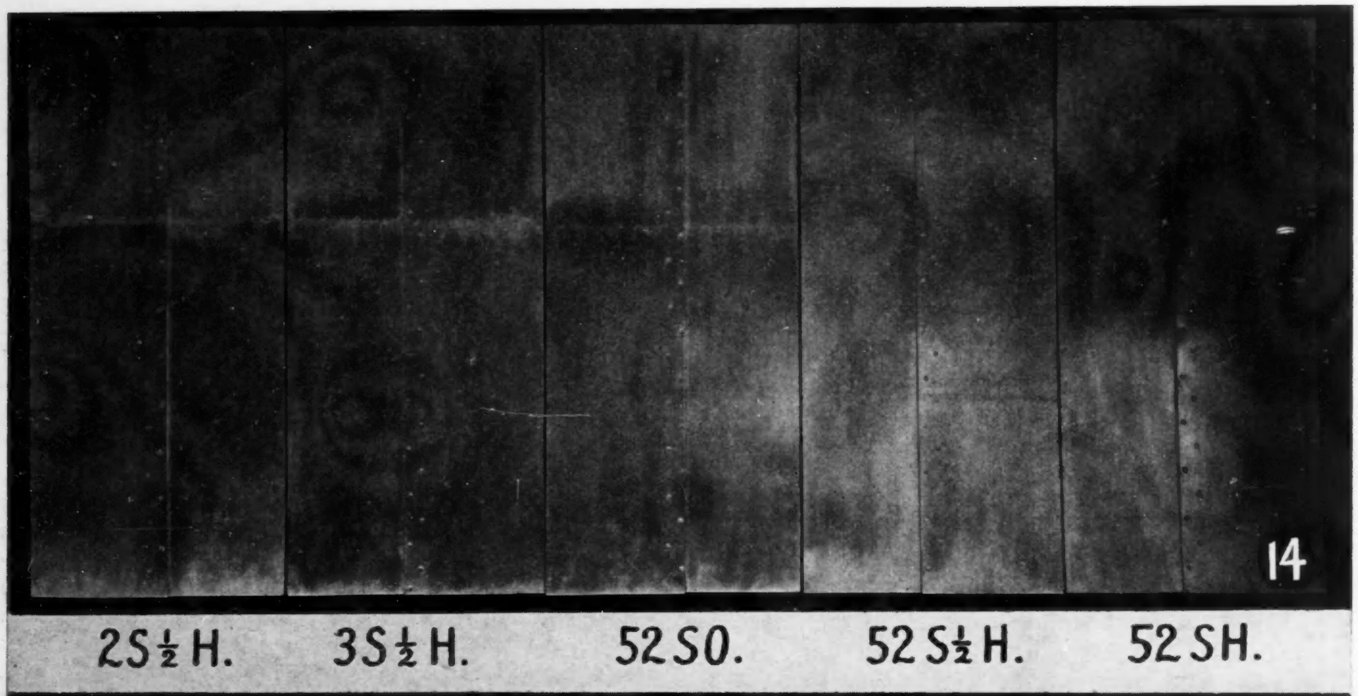
Production speed in making spotwelded structures varies from 5 spots per min. for large unwieldy parts such as gas-tank assemblies to 150 spots per min. for small parts that can be handled easily by one man. The making of a single spot takes only a fraction of a second, and the major portion of the time is required to index the part to the next spot. The great variation in the type of work done makes it difficult to be more specific in this connection. In seamwelding, speeds

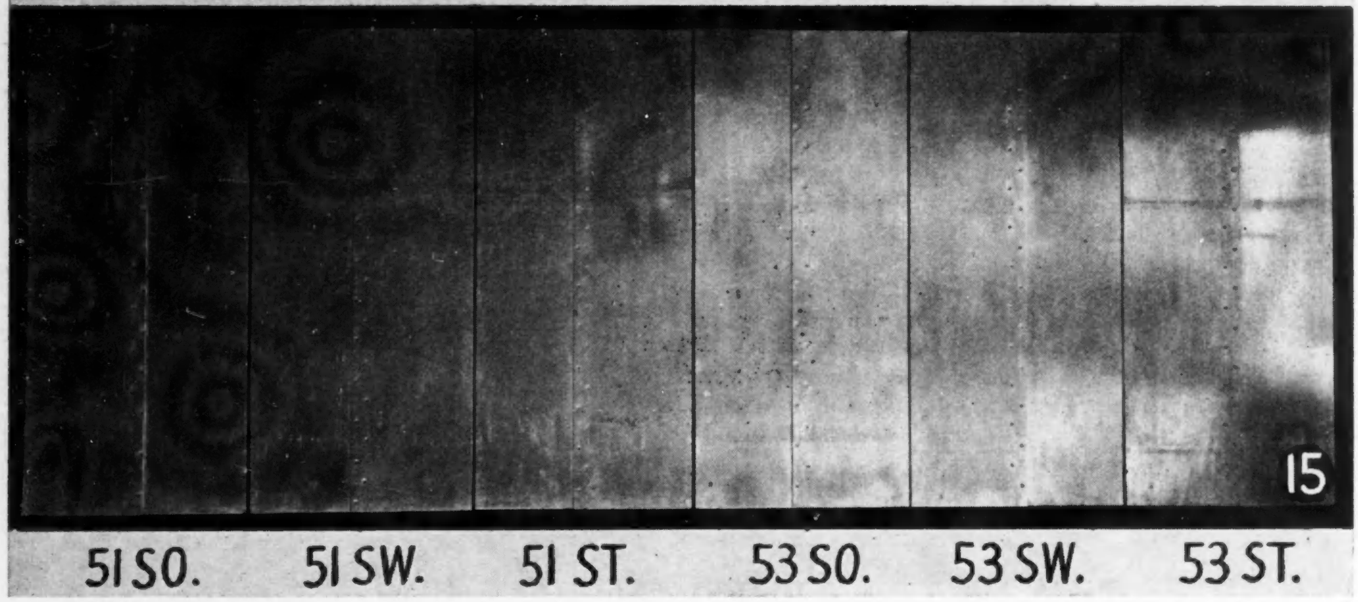
of 1 to 6 ft. per min. are attained for gas-tight or liquid-tight welds, and from 6 to 15 ft. per min. if the spots are placed intermittently. In this case also, due allowance must be made for handling the part. As the indexing between the welds is automatic, the idle time is substantially less than with spotwelding.

The use of jigs and fixtures to hold and align the parts is an important feature in lowering the overall cost. Such jigs should be light and flexible to permit rapid movement of the parts. A simple fixture for supporting a tank is shown in Fig. 8 which permits the welding to be carried out by a single man. A similar fixture operated by two men has been used in welding tanks up to 250 gal. in capacity and weighing 100 lb. A movable table of the type shown in Fig. 10 has been found useful for spotwelding stiffeners to large flat panels.

No non-destructive tests have been developed that will show the strength or quality of a resistance weld in the completed part, and inspection is limited to a visual examination of the surface for cracked or "burned" welds. Control of the quality of the welds is, of necessity, ascertained by making periodic test samples of the same gage and alloy as the object being welded, and by testing these samples by tearing or in a tensile-testing machine. Further assurance that the correct machine set-up is being maintained is obtained by providing instruments to check each welding cycle.

Correct adjustment of the current from day to day or week to week is done by installing a current transformer on the primary circuit of the welder and reading the current on a conventional ammeter. The welding cycle is too short to permit the needle to come to rest, but the deflection for any one setting of welding current and time is constant and proportional to the heating effect at that setting. A record of the

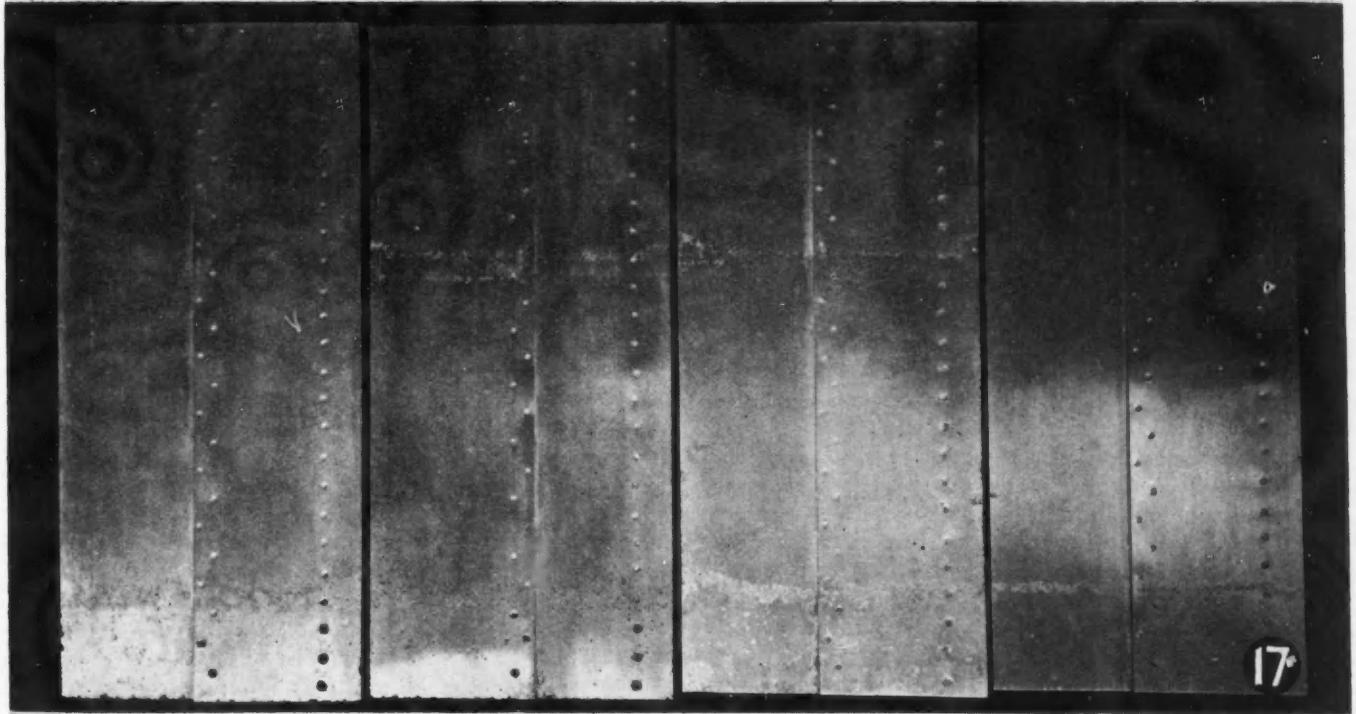




Figs. 14, 15, 16 and 17 – Spotwelded Corrosion-Test Panels Exposed

deflection is made, and settings can be duplicated later for further work. A check on the machine settings from weld to weld is made in a similar manner except a variable resistance is provided in the ammeter circuit to permit setting the instrument to give a fixed deflection. At this deflection the hand is made to intercept a light beam which, by means of a photo-electric cell, actuates a bell. A change in machine set-up while welding, to increase either the time or the current, will increase the deflection and the bell rings twice. A change to decrease the time or the current decreases the deflection, and the bell does not ring. In either case, however, even though the operator's eyes and hands are busy following the work, he can stop welding and correct the faulty condition immediately after it occurs.

17 ST. 17 SRT. ALCLAD 17 ST. ALCLAD 17 SRT.



42 ST. 24 SRT. ALCLAD 24 ST. ALCLAD 24 SRT.

To Alternate Immersion in Hudson River Water for 10½ Months

Table 1 – Breaking Loads on Spotwelds in Various Aluminum Alloys

Alloy	Breaking Load, lb.
2S½H	200
52SO	240
52S½H	450
Alclad 17ST	350
Alclad 24ST	360
53ST	350

Note: These figures represent the average shear strength per spot obtained on five or more 1 in. wide two-spot test specimens. All specimens were made from sheet 0.032 in. thick.

In spotwelding aluminum a spheroidal cast "bubble"-shaped volume is formed at the interface between the parts by the passage of the current. The best combination of strength, toughness, and resistance to corrosion is obtained if the weld extends about two-thirds of the distance to the surface of the piece. The strength in shear of a weld of this type is generally comparable to the strength of a rivet in the same gage and alloy.

As far as is known, there are no aluminum alloys that cannot be spotwelded, and the strength of the welds depends on the alloy being welded. The amount of cold work in the parts also influences the strength with the soft or annealed temper showing the least strength, and the cold-worked or heat-treated temper showing the highest strength. The breaking load for spots in some typical alloys is shown in Table 1. As the size of the spot is a function of the thickness of the material, it follows that the strength depends on the thickness. Fig. 11 shows the variation in shear strength for various gages of two of the commonly used alloys for spotwelding purposes. All combinations of gage and alloy have not yet been tested, although the scope of the data is being extended rapidly where specific cases of immediate interest occur. Each point on these curves and the two groups following, represents the average breaking load per spot determined by testing five duplicate 1 in. wide two-spot test specimens. The specimens were tested by loading the spots in shear.

Another factor that is of importance in using spotwelds concerns the effect of the distance between the center of the spot and the edge of the joint. Placing the spots too near the edge of the sheet permits squeezing out of some of the molten metal because of lack of mechanical support around the weld. When this squeezing out occurs, there is a loss in strength. The effect of this variable in 52S½H sheet is shown in Fig. 12. As shown on these curves, the welds should be placed at least four times the thickness of the sheet from the edge.

The distance between the spots is also important. Spacing the welds too close together provides a shunt for part of the welding current through the adjacent spot. The magnitude of this effect varies with the gage of the material and is shown quantitatively for 52S½H sheet in Fig. 13. In this case it does not follow that spotwelds should not be spaced closer than the minimum spacing shown on the curve where full strength is obtained. If a closer spacing is desired, full strength can be obtained by increasing the current to compensate for shunting effect or, and this is usually the case, individual tests can be made to determine the strength of the spacing chosen.

Some work also has been done in determining the serviceability of spotwelds in resistance to fatigue or vibrational loading. No absolute values of fatigue strength have been determined as the tests were designed to permit the comparison of spotwelds with rivets in both tension and shear. Results of this work indicate that spotwelds will resist such loading as well as do rivets. Further evidence that spotwelds can be used in vibrating structures has been obtained from the standard 25-hr. vibration tests specified for airplane gasoline-tank designs, and a number of designs have completed the test satisfactorily.

Resistance of Spotwelds to Corrosion

The resistance of spotwelds in the commonly used alloys when exposed to various corrosive conditions, is being tested. In view of the good resistance to corrosion of the base materials in which the welds are made, such tests generally take a substantial time before comparative data are available on the welds.

In many cases spotwelds are exposed to nothing more severe than the atmosphere, and this exposure was chosen for one set of tests. In order to provide severe conditions, the specimens were exposed on the coast line at Point Judith, R. I., in such close proximity to the water's edge as to deposit salt spray on the specimens during stormy weather. After one year's exposure, tests on the specimens showed no loss of shear strength on the welds made in 2S½H, 52S½H, 53ST, Alclad 17ST, and Alclad 24SRT. Slight losses were obtained on testing the welds in 17ST and 24ST. Examination of additional specimens after two years' exposure showed no evidence to indicate that different results would be obtained if tensile tests were made at the time, and it was decided to expose the specimens another year before testing the next group. This testing will be done in June, 1937. The results in this test confirm earlier salt-spray tests.

Additional data have been obtained by exposing spotwelded panels to alternate immersion in Hudson River water at Edgewater, N. J. In this case, the panels are so exposed that, at hourly intervals, the lower portion is immersed continually in the water, the middle position is immersed alternately, and the top is exposed only to the atmosphere above the water line. The corrosive medium is brackish tide water from the Hudson River which also contains appreciable quantities of industrial waste.

The condition of these panels after exposure for 5½ months during the summer of 1935, and 5 months during the summer of 1936, is shown in Figs. 14, 15, 16 and 17. The panels were subjected to 6300 immersions during this period.

Under such severe conditions of exposure, the bare materials without paint protection are, of course, subject to some attack. Visual examination of the spotwelds, however, shows no preferential attack in the welds as compared to the parent sheet for welds in 2S, 3S, 52S, 53S, Alclad 17ST, Alclad 17SRT, Alclad 24ST, and Alclad 24SRT. As separate panels were tested to cover the range of commercial tempers and heat-treated forms of these alloys, the conclusion is justified that there is no apparent difference in the resistance to corrosion of spotwelds in the various tempers of the preceding alloys. The welds in the alloys 51S, 17S, and 24S, show some attack in the completely immersed and alternately immersed portion of the panel. This result confirms the result obtained with other corrosion tests: that the resistance to corrosion of the welds is not as good as the parent material in these alloys, and that another alloy should be chosen or the welds protected with paint coatings.

The Aircraft Trend in Body Structural Design

By Edward G. Budd
President, Edward G. Budd Mfg. Co.

STREAMLINING, introduced into the aircraft industry because of practical necessity, became a no less compelling force in automobile body design. Even though the power saving is not as great as with aircraft, it improved the appearance of the car, and people wanted it. And so a force as great as necessity mothered invention.

The body engineer must share the credit for the flowing lines of modern bodies with the steel industry for developing wide sheets of proper composition, with the press builders for producing the huge, powerful presses necessary, and with the ingenuity of the die makers.

The all-steel body is discussed, explaining its greater strength and stiffness and stressing its ease of assembly into complete units that can be transported easily to assembly plants.

Restraining factors in body design are given as what the public is prepared to accept and what it is commercially practicable for the manufacturer to produce.

Advantages of integral all-steel construction of body and chassis members are weighed against its disadvantages.

THERE is a point in all scientific development when human necessity ceases to be the mother of invention. At that point the inventor and the engineer are confronted by a force no less imperative than necessity, yet far less logical. I refer to the compelling force of human desire, which is seldom very rational.

Suppose for a moment we take it for granted that necessity has behaved as the great arbitrator, settling all disputes between those who championed the composite type of automobile body and those who upheld the all-steel automobile body. Suppose it is conceded, in the face of overwhelming demand, that the all-steel body is the ultimate in practical construction.

[This paper was presented at the Annual Meeting of the Society, Detroit, Mich., Jan. 13, 1937.]

We are then confronted by an interesting problem. Have we reached the point where logic and necessity are supplanted by ordinary human whim, or will radical changes in automobile design and motive power create a new necessity?

The achievement of the modern flowing lines in the automobile body with steel as the material for surface form, is not entirely due to the ingenuity of the body engineer. Other developments in machines and mechanical practice have contributed in no small measure to shape the dreams and designs of the artist and the body engineer to a reality.

We must remember the astonishing developments in the sheet-steel rolling industry, enabling a sheet of cold-rolled steel to be made wide enough to produce an entire side-panel, extending from the hood-ledge to the trunk opening, and from sill to roof line. And we must pay tribute to this same ingenuity which at length produced a sheet of steel large enough to stamp out an entire roof panel without a joint.

Prior to this development sheets of the required width could be obtained only by flash-welding narrower sheets. Yet, even with the wide sheets, the accomplishment would not have been complete without the press builders who developed larger presses with increased power. Then, too, enormous dies had to be designed, involving a new study of stresses and strains – a new application of the art that controls the flow of sheet metal in the die under the tremendous power of the presses.

All-Steel Roofs Add Stiffness

The all-steel roofs, thus made possible, have increased greatly the stiffness of the entire structure. The deeply shaped draw panels form an ideal basis for the main strength member. The roof panel actually could be made of thinner sheets in many cases, but the engineer is limited in this respect by the inherent ability of the metal to withstand deep-drawn formation in the dies. To secure the proper shape we are compelled to use sheets thick enough to be drawn and worked without breaking or tearing.

The all-steel shell, when welded into a unit, needs very little reinforcement. However, along the door header, around the door openings and windows, at the instrument board and along the sills, channel-shaped reinforcements are welded into place, forming a box section – the strongest and lightest form of structure. These reinforcements are designed so that the trim strips to which the upholstery is fastened are inserted readily and quickly, and firmly held. The whole design of the reinforcements is aimed at making it commercially practical to perform the necessary operations of assembling and welding, with the welds placed where they will either be

covered or finished readily so as to be invisible when the body is painted.

All of these are eminently practical considerations, but it was practical necessity influencing another industry that has been responsible for the trend toward the streamline automobile body. Streamlining, a necessity in aircraft design, became a no less compelling force in automobile body design. Even though the power saving that resulted was not as great as it is in aircraft, still streamlining improved the appearance of the car. And human beings wanted it, and so a force as great as necessity mothered invention.

This force, the appreciation of the buying public for flowing lines for exteriors as well as for modernistic straight lines for furnishings and appointments, indicates the trend so far as form is concerned. And, fortunately, our material offers no resistance.

For sheet steel has become most obliging in recent years. If a few rules of control are followed and if its individual types – one might say, personalities – are understood, it will gracefully, like the shapes evoked by the sorcerer, take almost any shape required of it. Engineers are not sorcerers but, when we see how the public's desires have been met, we can be pardoned if we sometimes feel like sorcerers who have used a substantial magic to work wonders.

These shapes cannot always be rationalized by saying that, by deformation of the flat sheet or strip, the elements of the metal itself can be distributed so as to produce maximum strength with a minimum weight. But we have not forgotten that the ultimate goal of the body engineer is a pleasing and practical design together with strength and a minimum of weight. That this purpose has been accomplished with due regard for the public taste and demand is greatly to our credit.

Streamlining itself is more than 30 years old. Nature has had it for untold thousands of years. One of my colleagues, a gifted and imaginative man and fond of paradox, has asserted that, according to the strictest engineering logic, it is quite possible to make a design here and now that will embody developments almost certain to take place within the next ten years. The methods used to evolve such a design, he says, would be the methods of biologists who construct, on logical premises, the creatures on another planet. At the same time, this man says, the design if offered now almost certainly would meet with a bad reception. The point he makes is that it is possible to be right, but to be too far ahead of the times.

Restraining Factors

The factors restraining us are, and always will be, what the public is prepared to accept and what it is commercially practical for the manufacturer to produce with the available materials and tools. So far as the newest trend in automobile body construction is concerned, there does not seem to be any reasonable doubt that the public's attitude will be favorable. It is the factor of commercial practicality which we must consider.

The trend I refer to is toward the integral construction of body and chassis members which entirely eliminates the separate construction of body and chassis. One of the greatest advantages of all-steel bodies, as compared with composite wood and steel bodies, has been the possibility of building them in completely assembled and finished units that can be transported economically to the assembly plant of the automobile manufacturer and assembled into the complete body in a period measured by minutes. Further development of the integral construction of body and chassis would be an additional step toward simplifying assembly problems and toward realizing to the maximum the structural advantages introduced by the all-steel body.

If this new method of body-chassis construction gains ground – and it seems probable to me that it will – the art of flash-welding again will play an important part in securing the fine, homogeneous unit of sheet steel that will be required. No other material will be able to supply the structural and physical effects that sheet steel can provide in this type of construction. Its inherent qualities lend themselves admirably to the tasks that will be imposed on the various members of the structure.

In Europe, particularly, considerable attention is being directed toward this method, and some foreign manufacturers already have adopted the method for standard models. Numerous experiments have been made with the method in this country, but so far they have not resulted in any large-scale production. It has been said that the method may be practical in Europe where production is comparatively limited, but that manufacturers in this country who think in terms of mass production have to consider ease of assembly, sequence of operations, and the additional floor space required since the unit becomes longer due to the forward extension to support the engine and front axle.

Under the new system, accurate familiarity with the placement of engines, springs, and all related parts will, of course, be essential. Power equipment will have to be assembled after the unit has been built, finished, and trimmed with upholstery and hardware. This method will require care on the part of workmen to avoid injury to the body finish. As to weight saving, there is a very small margin. With regard to cost, we have a more doubtful point. At present a chassis can be produced for, say $9 to $15. Can we add from $9 to $15 to the cost of the present body and produce a combination chassis and body unit? We will have to do some close figuring.

With due regard to all the problems involved there are many obvious advantages to a system of construction that eliminates the separate body and chassis units and combines them into one homogeneous structure, ready for the motive power, spring suspension, and rolling equipment. Adoption of this system by the automobile industry would constitute what some may consider a radical innovation, but the wide chassis, steel roofs, short cowls with long hoods, and many other things that are accepted today were labeled radical innovations at the time of their conception.

One Airline's Fleet

AMERICAN AIRLINES has 60 airplanes of which 50 are actually in daily passenger-carrying service, the other planes being necessary for blind-flying instruction, route checking, and other similar duties. These 50 active planes fly nearly 50,000 miles per day or approximately 1000 miles per plane per day. They fly at all hours of the day and night. There is never a dead period when some plane is not flying. The lowest number of planes that are flying on schedule at any one time is in the very early morning and is never less than five planes. The highest number is in mid-afternoon and is 32 planes.

Excerpt from the paper "Problems in Airline Operation", by R. S. Damon, vice-president, American Airlines, Inc., presented at the Regional Meeting of the Society, Dallas, Tex., Oct. 9, 1936.

Problems in Design and Construction of Large Aircraft

By R. J. Minshall, John K. Ball, and F. P. Laudan
Boeing Aircraft Co.

THIS paper contains a general discussion of the problems involved in arriving at the final design of large airplanes having gross weights of 35,000 lb. up to approximately 100,000 lb. It deals with certain aerodynamic features that evidence themselves when airplanes are increased to the sizes just noted. Comments are made on wing-taper airfoil sections and the possibility of increasing the *L/D* in large airplanes, and on certain factors that enter into the control of large airplanes.

A rather detailed account of structural considerations is undertaken; it shows the methods used by the aircraft designer in scaling up his ideas from airplanes of a year ago to the larger types to follow. Several types of aircraft construction are discussed, showing the advantages and disadvantages of each type. The question of strength-weight ratios also is discussed.

The methods of analyzing semi-monocoque and pure monocoque structures are reviewed, and examples are given of the analysis procedure. The paper illustrates static-test methods on airplane parts.

IN 1929 the Boeing Aircraft Co. built the Boeing Monomail. This airplane was a low-wing cantilever monoplane with a single engine and a retractable landing gear. Although this airplane had a wing span of only 59 ft. and a gross weight of 8000 lb., it provided the first rung on the ladder of the development of larger airplanes having high performance.

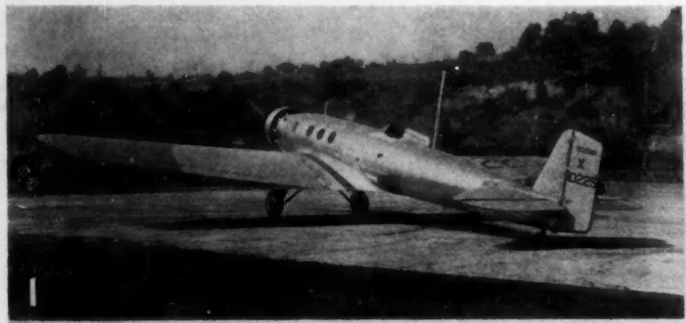
Many large airplanes have been built in the past, such as the Barling Bomber which had six Liberty engines and a gross weight of 42,569 lb., but these airplanes did not possess the high performance as measured in terms of the performance obtainable in the larger airplanes built today, and which will be in evidence tomorrow. No modern airplane, large or small, not having a high speed of well over 200 m.p.h., would be considered as having sufficient merit to warrant its construction today.

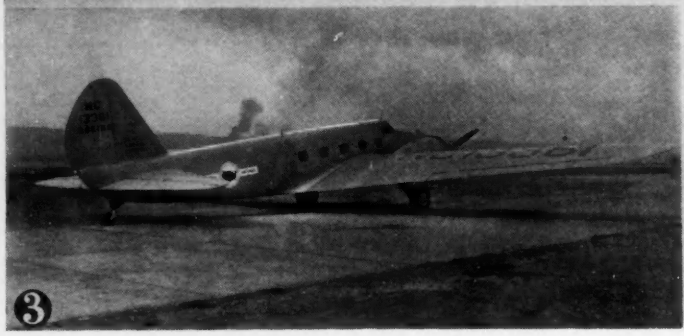
The old Boeing Monomail did not have a great deal of performance, but many features of this airplane were undertaken with the definite thought in mind that larger airplanes were to come, and that this airplane would make an excellent trial horse for certain features of design. For instance, this airplane had a smooth-skin wing of cantilever construction. The rivets were countersunk throughout the entire external covering to approach as closely as possible a maximum cleanness, giving the lowest possible skin-friction drag. The landing gear was made retractable to rid the airplane in flight of this large portion of its parasite drag.

The cantilever wings of this airplane were not strictly of the skin-stressed type. They were of a two-spar type with the skin covering furnishing the required torsional stiffness. It was then recognized that the spars of the future large airplane would be more efficient as trusses than as web spars, so the truss-type spar was used to provide data for the design and construction of larger aircraft to come. This proved to be wise procedure since the largest airplanes now being considered by this company have wing spars of the same type as were used in 1930. Although our concept of the proper manner of distributing the stresses in a cantilever wing has changed somewhat, it is quite remarkable that in seven years we are now able to design airplanes having gross weights approximately ten times that of the old Monomail and still find that our tubular trussed-type spars were an excellent method of solving the problem. The Boeing Monomail of 1929, the Boeing Y1B-9A of 1932, the 247 of 1933, and the 299 bomber of 1935 (Figs. 1, 2, 3, and 4 respectively), all had this type of spar. Future types of even larger dimensions, now in process, also will contain trussed spars. (Further comments on the design of spars and their manufacture will be made later in this paper.)

From the aerodynamic standpoint, large aircraft present some very interesting problems. For instance, the selection of airfoils will be influenced by the high Reynolds number available. We now have under construction aircraft having a Reynolds number as high as 14,000,000 at landing speeds of

[This paper was presented at the National Aircraft Production Meeting of the Society, Los Angeles, Calif., Oct. 17, 1936.]





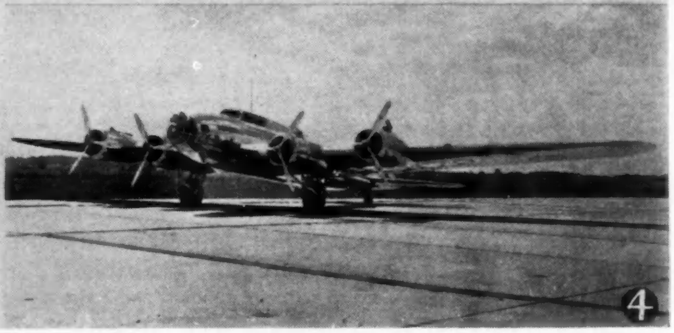


Fig. 1 – Boeing Monomail

Fig. 2 – Boeing Y1B-9A

Fig. 3 – Boeing Model 247-D

Fig. 4 – (*Courtesy U. S. Army Air Corps*) Boeing Model 299

65 m.p.h., so that our selection of airfoils for these large airplanes has been predicated entirely on the results to be obtained at high Reynolds numbers. (See Fig. 5.) Due to this same Reynolds-number effect a designer may, by careful selection, obtain an airfoil that will have a high degree of efficiency at cruising speed and still possess excellent characteristics at the stall with flaps. It is also evident that greater liberties may be taken with planform taper, since stalling of the tips of large aircraft will not be so predominant as with small airplanes, due to the large chord still available at the tip when high taper is used.

As will be shown later large aircraft must, in many details, be designed on the stiffness or rigidity basis. Since it is evident that larger airplanes will possess the same performance as the present airplane of 80,000 lb. gross, we must apply all the knowledge we possess to avoid and prevent the ever-present possibility of flutter. The Boeing Aircraft Co. recognized this factor when building the Monomail and developed a non-reversible aileron control that prevented flutter if it were to be present. We might, in several instances, be accused of overdesigning our tail surfaces, but the fact remains that we have not had any trouble from tail-surface flutter which, we believe, can be avoided easily by providing sufficient rigidity in certain places. For instance, the elevator connecting torque member is given very careful attention as to rigidity so that the frequency between elevators will be high. Dynamic balancing or static balancing of movable surfaces is only resorted to when non-reversible controls cannot be installed. It is quite obvious that adding lead weights to an airplane for the purpose of static balancing is not an economical way to produce the proper results.

Another problem that is open to considerable research in the design of large aircraft is that of control. It became quite evident several years ago that, when airplanes exceeded a gross weight of approximately 20,000 lb., it would be necessary to provide some assisting device for the pilot to enable him to operate the surface controls in flight. There are, no doubt, several means of accomplishing the proper results. It has been suggested, for instance, that the automatic pilot be used as a servo to follow up the pilot's maneuvers to control the airplane. Booster controls, such as compressed-air cylinders, have been suggested also. It is not believed, however, that all these devices, which depend upon mechanical contrivances foreign to the general flying characteristics, are the proper approach to the problem. The reason for this belief is obvious, since failure of any such servo or booster device would not enable the pilot to carry on in the face of emergency conditions.

The Boeing Aircraft Co. has carried on full flight tests for the past 3 or 4 years on a Model 80A transport and a 247-D transport in an effort to obtain a satisfactory means for controlling large airplanes. One of the old Model 40B single-engined mail planes also was put at our disposal, and several interesting tests were conducted on this same problem.

We now use, in several instances, a combination of balancing, trimming, and controlling tabs to accomplish our desires regarding reduction of control forces in the cockpit to a point where the pilot can fly the airplane very easily. In fact we have been able to evolve a scheme of control wherein an airplane having a gross weight of 35,000 lb. can be flown with one hand throughout the entire range of flying speeds.

This whole program of flight control requires a very careful and systematic procedure. It is quite obvious that large steps could not be taken since, when using such things as balancing tabs, it is quite easy to get into trouble so far as over-controlling is concerned. Our research work is being continued in this direction since it is believed that reduction of control forces quite properly should be obtained by some means that depend upon the airplane's flying speed. Figs. 6, 7, and 8 show experimental control-tab installations.

So far we have dealt only with flight characteristics of large airplanes. However, one of the biggest problems that the airplane designers must face is that of ground-handling characteristics. The larger the airplane becomes, the greater the requirement for good brakes. It is very necessary that the pilot be given some means of quickly operating the brakes in order to handle a large airplane on the runways now available. The same problem is true of brake controls as exists for flight controls. Airplanes having a gross weight of greater than 20,000 lb. must have a servo means that will aid the pilot in applying the brakes through the accepted brake pedals which are now used universally.

We recently have installed air brakes on an airplane having a gross weight of approximately 35,000 lb. and have found that this means of energizing the brakes is excellent except for one difficulty which will, no doubt, be overcome. This difficulty is lag in the brake system. In other words, the pilot has a tendency to over-control the brakes by applying a greater amount than is actually necessary due to the fact that he is unable to feel the brakes until a large amount of air has been applied. The same factor prevents releasing the brakes quickly due to the time element involved when discharging air from the brakes. Oil-operated brakes, with a booster system involving air operation at the brake pedals, may prove to be an excellent means of overcoming the time-element factor.

After good brakes and means of rapid operation are developed, it also appears that it will be difficult to stop a large airplane with the wheels and tires now used. It was not at all difficult for the pilot to slide the wheels on the Boeing 299 bomber, and the airplane would keep right on going as though nothing had happened. As far as tire conditions that relate to braking are concerned, it may be that dual wheels, placed side by side, will present certain advantages.

The second section of this paper will be devoted to the more detailed description of structural considerations in the design of aircraft. The third section will enlarge upon certain manufacturing difficulties that have been overcome and will illustrate some of the various phases through which large aircraft parts are processed during fabrication.

Structural Design of Large Aircraft

The design of a large airplane presents to the aircraft structural designer a maze of intricate and intriguing problems. The details involved are considerable, sometimes rather appalling when viewed en masse, but the designer must go through his past experience, sort out the ideas that apply, test or study out theoretically for that which he does not know or to which he cannot extrapolate, then piece together the details until he emerges with a structure that is sound and satisfactory.

In going from one design to another of the next size, a scaling up of standards is important, particularly with respect to minimum sizes. In this matter there are no rules or specifications to follow, the only criteria being simply past experience and sound judgment. Rigidities tend to decrease with an increase of airplane size and this fact cannot be overlooked in many cases, although probably for many parts to a degree yet undetermined, extreme rigidity or high natural frequency may not be of great importance. Further, the demands upon the modern structure are continually becoming more and more severe, in spite of which demands structural weights must continue to become a smaller portion of the total if the desired degree of efficiency of design is to be attained.

The following paragraphs take up some of the problems found in modern structural design of the large airplane. These examples have been picked more or less at random to give only a general cross-section of the great mass of structural considerations required. No attempt is made to go into complete detail or to get involved in extreme technicalities as each item, to be presented completely, could well take the space of this entire paper.

The actual wing-design loads for large airplanes are, in their general method of solution, comparable to those for small airplanes. The differences arising from various maneuver load factors and the means of allowing for gust loadings are covered by the Army, Navy, and Bureau of Air Commerce specifications so they do not need to be dealt with here. However, an item of major significance present in the wing of a large airplane and not usually of any importance in the smaller ship, arises from the distribution of dead weight such as fuel, oil, motors, bombs, equipment, and so on. As airplanes increase in size, more and more of their weights are shifted to the wings. For fixed weights this factor may work to the benefit of the structure in flight conditions as bending moments and shears are reduced.

But very likely, then, many of the wing members will be determined by landing conditions. This method of determination is particularly true of flying boats where the landing factors are very high. In any event, the use of large weights in the wings calls for structural investigation of a far greater number of loading conditions than otherwise would be necessary. The number of weight-distribution conditions necessary to analyze depends upon the class and number of the variable weights, but it has been found, and will be more important as greater sizes are designed, that two and sometimes three distributions for each flight and landing attitude are

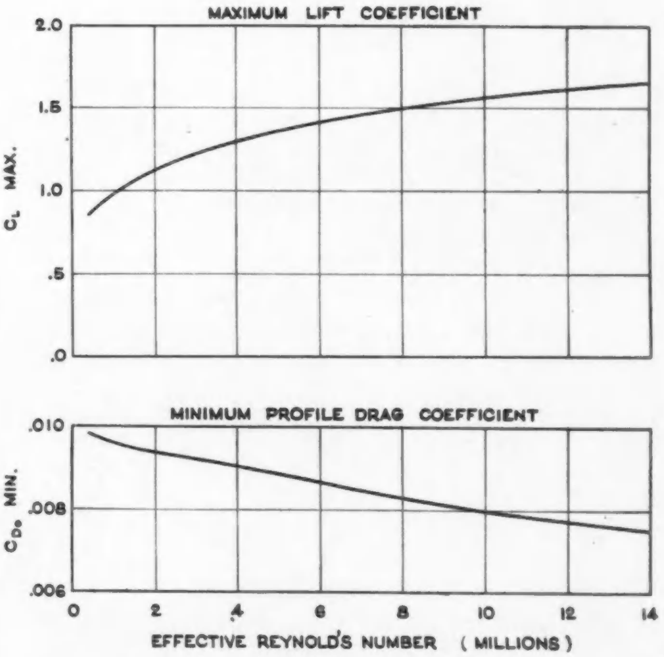


Fig. 5 – Typical Airfoil-Section Characteristics – Variation with Reynold's Number

necessary. Members affected by dead loads are, of course, critical for the condition of lightest gross weight, the gust acceleration being highest then. Members affected by wing torsion and also spar web members have been found to be particularly susceptible to dead-weight variation.

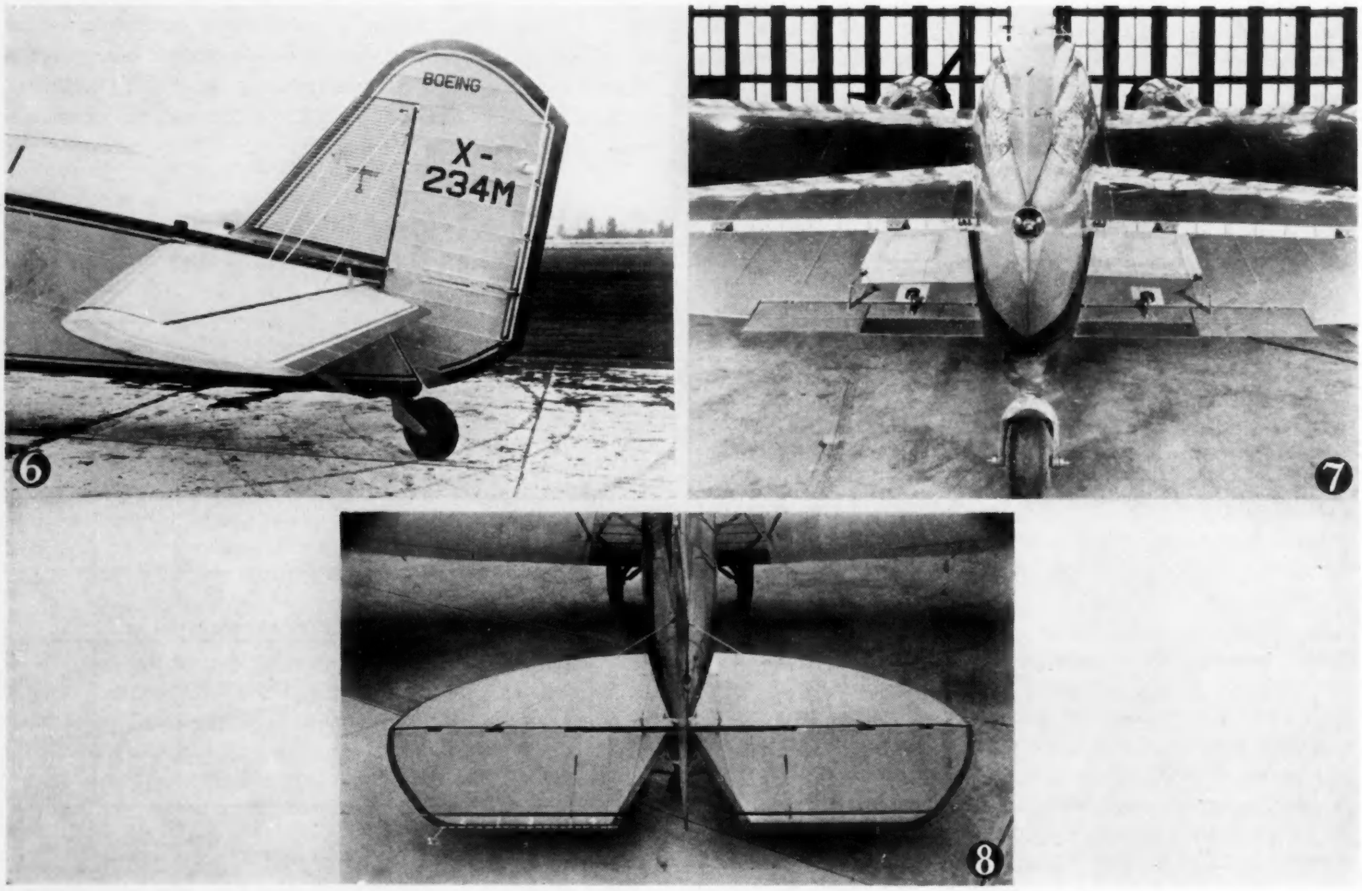
The flight attitudes for flap down, too, have come in for extra study in the case of the large airplane and, in some cases, there is a possibility that most of the wing structure would bear investigation under flap-down loadings. For large cantilever wings equipped with partial-span split flaps, the Boeing Aircraft Co. at first expended considerable time in investigating the structures for possible flap effects that might arise, but the loadings on any of the major structure (except trailing-edge ribs and flap supports) have seldom been of great importance. A very worthwhile step in the elimination of design conditions has been proposed by the Bureau of Air Commerce in a bulletin dated Oct. 1, 1935. The proposal eliminates the necessity for checking for flaps down by the simple expedient of choosing a suitable wing-moment coefficient (based on the relative speeds and coefficients for flaps down and up) for the normal flight conditions. To date, the results of using this method have proved to be extremely reasonable.

In the matter of the detail design of a wing structure, the type of construction probably, in all cases, is controlled by the experience of the designer, past practice, test data available, and the dictates of the airplane specification. The case of the Boeing Aircraft Co. is no exception, and the type of cantilever-wing construction the designers are adhering to at the present time is the result of continued development, experience, and the accumulation of test data over a period of several years. This construction employs two truss spars with tubular members, corrugations (aluminum alloy) between spars extending spanwise, flat-sheet covering (aluminum alloy) over the section between spars and over the leading edge, flat-sheet covering or else fabric over the trailing edge, and ribs with "hat"-section chords and tubular web members. Fig. 9 gives an illustration of a typical wing. The advantages of the metal covering are too well known to be enumerated here. Likewise, the beneficial effect of corrugations in giving torsional stiffness to a wing while resisting bending moments at the same time is fully realized. However, it may be interesting to enumerate the advantages of the tubular-spar construction. In this connection it should be noted that the tubes used are of square, rectangular, and "barrel" section, the last having two flat sides for ease of attachment and two rounded sides to give high compression strength. The advantages claimed are:

(1) A minimum weight for very deep spars with high shear loads is obtained.

(2) Webs subject to local or general wrinkling are avoided. For light weight, I-beams necessarily must have thin webs ("Wagner" beams) and may be subject to undesirable wrinkling at low factors.

(3) Greater inspection facilities, particularly when removable leading and trailing edges are used.



Figs. 6, 7 and 8 – Experimental Control-Tab Installations

(4) Tubular members have inherently high local crushing strengths. This feature and their essential character of compactness permit the use of members of minimum external dimensions.

(5) Tubular members are well adapted to the use of high-strength steel (180,000 lb. per sq. in. tensile strength) and 24SRT aluminum alloy.

(6) The tubular sections used (by reason of their shape) permit ease of attachment of adjacent parts.

With respect to the details of structural design in the Boeing type of wing, one of the most interesting is the problem of the relative thickness of the corrugations and covering. The first impulse of the designer who is well versed in his monocoque design is to use skin or covering as thin as possible as the best strength-weight ratio is thereby obtained. However, tests have shown that this is not always the best practice. For instance, torsion tests on cylinders constructed of corrugated and flat sheet (see Fig. 10) have shown that corrugations are only about 50 per cent as effective in resisting shear as the skin. Thus, in a wing where high torsions exist, the choice of skin thickness should not be too low, as material is needed simply to resist shear and the skin provides the most efficient medium. Also, the amount of wrinkling permitted in the skin when the corrugations deflect elastically under compression loads is important. Too thin a skin will give excessive wrinkles at low factors. The conclusions drawn, as a result of the cylinder tests mentioned and certain wing tests are that, with skin of a thickness equal to approximately one-half of the corrugation-material thickness, there need be in the usual wing no worry about the effects of torsion or of local wrinkling at low factors.

Further problems of wing construction may be illustrated best by the photographs of test specimens herein. Fig. 11 shows a few of a large number of gusset test specimens. Theoretically exact gusset design probably will never be possible, but tests on typical gussets have shown that they can be designed, easily and well, on the basis of arbitrarily computed shear and tensile stresses. Unfortunately, details are too lengthy to be given here but it can be said that, in the hands of an apt designer, gusset design may approach a fine art. It has been found to be extremely beneficial to have several gusset-test specimens with their test loadings recorded on them available for the draftsmen. It then becomes relatively easy to pick out a test gusset with a loading condition similar to that on hand and design the new gusset in the same fashion. Fig. 12 shows a typical "U" gusset necessary to attach a heavily loaded compression strut to a spar for a large airplane and gives an interesting side light on the sizes being designed nowadays.

To attain the best strength-weight ratios from tubular spar members, tests are as necessary on these as they would be on other types of sections. Fig. 13 shows typical test specimens. It has been found that, by using high-strength steel and aluminum-alloy tubes, very high crushing values could be obtained, equal or better in some cases of low width/thickness ratios to the tensile strength. Further, it has been shown for the design of short columns that the Johnson parabolic curve, starting at the crushing strength (or tension strength when this value is less) rather than at the specification yield point can be used. Fig. 14 shows test results of a typical case. The test values recorded thereon are taken from tests of steel tubes with actual (test) tension strengths in the neighborhood of 160,000 lb. per sq. in., but the values have all been corrected to a common strength basis for the sake of presenting a uniform picture of an entire group. This and other tests have indicated readily to the investigators that the commonly accepted idea of basing upper limits of column strength on the specification yield point has little merit, particularly as this value, in the case of heat-treated steel tubes at least, has proved to be an extremely erratic quantity. This conclusion may sound like heresy, considering the number of text books that come out flat-footedly with the statement that elastic instability and consequent failure will result if the yield point is exceeded, but common sense, as well as tests, indicates that there is no precipitate drop between the crushing stress at a low or ineffective slenderness ratio and one somewhat higher. Conversely, of course, the column curve may, and does, start below the yield point in the case of tubes of poor form factor or inferior material, or sometimes as a result of inefficient connections.

Reinforcements

The exigencies of providing for equipment frequently are exasperating to the structural designer. It seems that someone is always finding it necessary to put a hole in an otherwise well-designed structural unit, and the designer must find some adequate method of reinforcing it. A typical case is a hole for a dump valve in a corrugated wing surface. Fig. 15 shows the results on tests of a typical hole. Both specimens, tested in compression, failed in the corrugation, not in the reinforcement provided. But, with the round-hole reinforcing shown on the left, there was a loss in efficiency, that is, the concentrated stresses near the hole caused the corrugations to fail prematurely, the average failing stress being much lower than for a plain corrugation. The larger panel with the odd-shaped reinforcement took the required load without an efficiency drop. The shape of the reinforcement, suggested by pictures of photo-elastic tests, made the difference between a good panel and an unsound one.

Truss-spar design requires the considerations of secondary bending effects in the spar chords. Various theoretical studies have been made, but the methods are long and cumbersome, and comparison with test results have shown the theoretical stresses to be of little value and even very erroneous in cases. Theory shows variable moments and a tendency toward "S" curvature in the chords between the panel points, but it seems that the more probable case, at least for practical purposes, is the general, uniformly varying curvature of the deflected wing. The simplest allowance for secondary effect in the chords is to base the bending on the radius of curvature of the truss under load, using a factor of 2 (or one-half of the actual radius) to allow for tendencies toward reversal of curvature. The idea is not new, having appeared in certain specifications for some years. It sounds cumbersome but, in its simplest state, it is extremely easy to apply as the reciprocal of the radius of curvature of the wing equals $\frac{M}{EI}$ of either the wing or spar. Consequently,

$$M_c = \frac{M_w E_c I_c}{E_w I_w}$$

Where:

M_c = secondary moment in chord.
M_w = wing moment.
E_c and E_w = moduli of elasticity of chord and wing.
I_c and I_w = moments of inertia of chord and wing.

Considering a square-tube chord, and applying the factor of 2 as mentioned previously:

$$f = \frac{M_w D_c E_c}{I_w E_w}$$

Where:

$f =$ the fiber stress.
and $D_c =$ the tube width.

In general, secondary stresses found by this method are 10 per cent to 15 per cent of the direct stresses, and in all probability are somewhat conservative.

One of the prime worries of the aircraft designer as he lays out a new design is just how much his wing structure will weigh, particularly when scaling up his ideas from smaller airplanes. Advances in the aerodynamic field, such as retractile landing gears, flaps, nacelle placement, high aspect ratio, and the continued urge for greater fuel capacities, have caused many a furrowed brow. Splitting up the wing structural weights into values occurring from the various causes has been found to give some help to the situation. As an example, Table 1 is given, showing data on two large wings. Wing No. 1 had an area (one side) of 960 sq. ft. and mounted one nacelle, two gas tanks, one oil tank, flap and aileron. Wing No. 2 had an area of 630 sq. ft. and mounted two nacelles, a landing gear, three gas tanks, one oil tank, flap and aileron. Considering the differences between previously designed wings and the one under consideration, the designer is aided in his estimating of items (2), (3), and (4) by such a tabulation. For item (1), the material affected by wing bending moments, a simple formula may be used for comparing the weights in two wings of the same general design and allowable stress intensities. This formula is:

$$w_2 = \frac{w_1 m_2 d_1 c_1}{m_1 d_2 c_2}$$

where:

w_1 and w_2 are the weights per square foot of two wings.
m_1 and m_2 are the root bending moments.
d_1 and d_2 are the root spar depths.
c_1 and c_2 are the root chords.

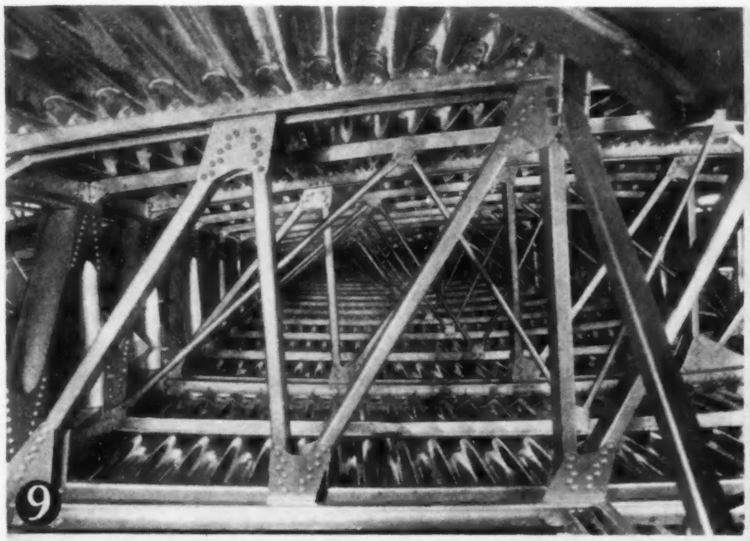
In monocoque fuselage design there are several items of more than passing interest. First, with large airplanes, care to obtain adequate torsional rigidity is believed to be essential. In scaling up from smaller models, the tail surfaces frequently increase in moment of inertia faster than the after end of the fuselage increases in size and stiffness. This condition makes for decreased torsional frequencies and, to maintain reasonable rigidity, the fuselage skin thicknesses often must be greater than those required by the dictates of strength alone. Second, body shear stresses tend to become higher in the large airplanes. Because of this factor, care must be taken to provide adequate continuity of all stiffeners, adequate end connections for stiffeners, and proper provision for stress concentrations at critical spots. Cutouts for doors, windows, and access must receive their share of study. Tests have shown that a reinforcement around a cutout, consisting of a skin patch and a frame of closed section with good ties to the adjacent stiffeners, can give all that is desired in the way of strength and stiffness. The use of longerons is more or less reminiscent of truss-fuselage design in the past but, if used judiciously, longerons still can serve the excellent purpose of providing load carry-through ability at large openings and distribute concentrated loadings into the adjacent monocoque structure.

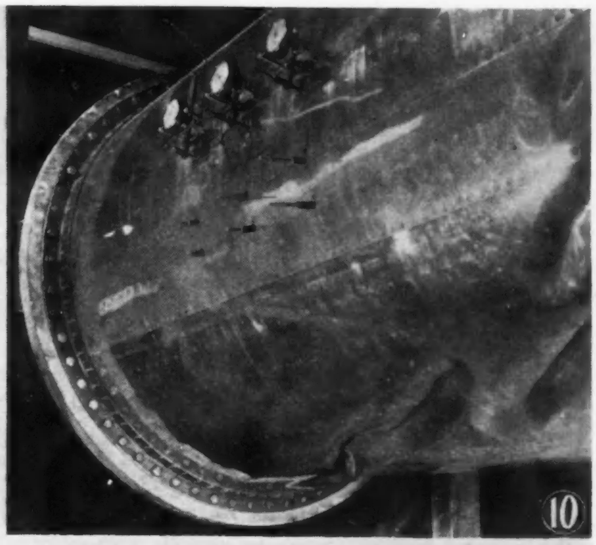
Table 1 – Weight Distribution in Two Wings

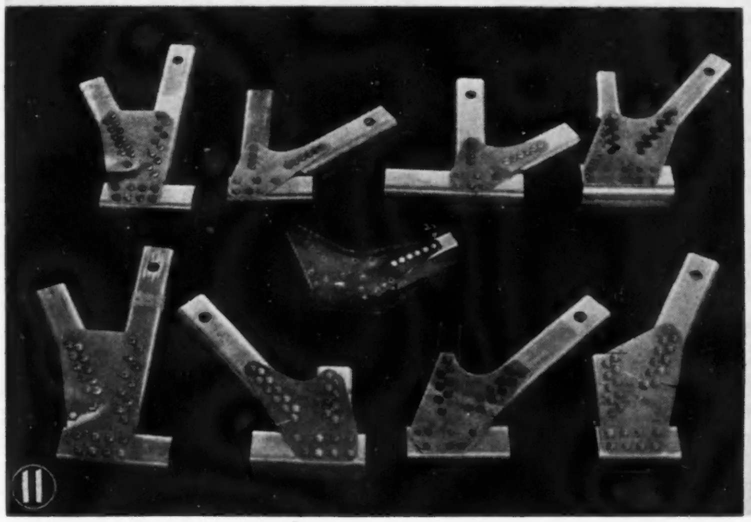
Item	Material	Weight per Sq. Ft., lb. Wing No. 1	Wing No. 2
(1)	Taking bending moments.	1.9	1.75
(2)	Chargeable to any metal wing of same specification (including miscellaneous covering, paint, equipment supports, walkways, tip and spar web members).	0.74	0.83
(3)	In ribs and members distributing air load (not including material required to carry flap, ailerons, nacelles, and so on).	0.40	0.46
(4)	Required to carry nacelles, fuel and oil tanks, flap, aileron, landing gear.	0.41	0.65

For the pure reinforced-shell fuselage, analysis methods for bending have by this time become a matter of mere routine due to the accumulation of test data over a period of years. The methods simply must take into account the crushing or column characteristics of the stiffeners and the amount of compression skin effective in the application of the beam formula. There is one pleasing characteristic of a fuselage: its extreme compression stiffeners may fail and the structure still will take more load due to the pick-up of adjacent members less distant from the neutral axis. The considerations for shear are not so simple, and the allowances a designer must make should be in keeping with the tension-field characteristics of the covering. If high-tension fields are present, they should not be overlooked, but there is no point in penalizing the stiffeners or riveting unnecessarily by applying extreme Wagner-beam (tension-field) ideas to skin purposely made reasonably thick to provide proper stiffness characteristics. Tests have indicated that stiffeners receive load according to the amount of skin wrinkling, paper-thin skin providing one loading extreme and thick skin the other. The amount of allowance to make must, at the present time, be largely up to the good judgment and experience of the designer.

Tail surfaces, in the past, usually have been designed by rather arbitrary loadings, these loadings being specified in the various structural requirements as minimum unit values or else as resulting from formulas involving coefficients of admittedly doubtful accuracy. However, the advent of the large, high-speed airplane has given rise to the necessity for designing to loads found by other more exacting methods, or at least to the necessity for checking the loads found by these methods against the arbitrary, specified loadings, in order to be certain that they may not be more severe. And, perhaps even of more importance than the mere size of the airplane and tail surfaces involved, is the now common usage of the constant-center-of-pressure airfoils. A steady dive condition for an airplane with a wing section giving a high-center-of-pressure travel automatically would yield high and safe stabilizer loadings, particularly as it has been customary to apply a 40 per cent additional loading on the stabilizer to allow for a reverse elevator action. Obviously, no such conservative loadings from the dive condition would result on the stabilizer of an airplane using a constant-center-of-pressure wing section. Hence, there is now, more than in the past,







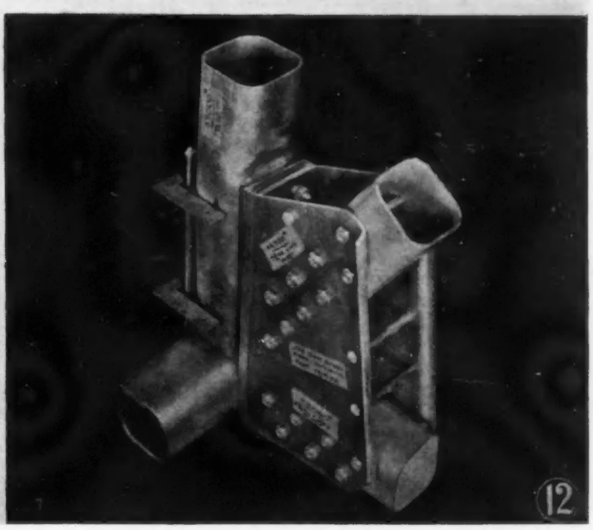


Fig. 9 – Typical Wing Construction
Fig. 11 – Gusset Test Specimens

Fig. 10 – Torsion Test – Cylinder of Flat and Corrugated Sheet
Fig. 12 – Typical "U" Gusset

the necessity for seeking out the most severe possible loads.

The following paragraphs list and explain the loadings that have been found to be critical for the cantilever tail surfaces of large, high-speed airplanes employing constant-center-of-pressure wing sections:

(1) Combined steady-dive and gust loading. This condition gives critical loads for the stabilizer and fin. The speed to be used is obviously the maximum design speed of the airplane.

Consider first the vertical surfaces. The initial loading before the advent of the gust is zero, or sufficiently close to that so that it may be neglected. The applied loading is then simply that resulting from the change of angle of attack due to the application of a sharp-edged gust. It is conservative, and desirable in the interests of rigidity, to determine the loading on the basis of the entire fin and rudder area (that is, neglecting the effect of a free or swinging rudder) but to apply the load only to the fin.

For the stabilizer, the condition is not quite so simple but relatively easy to determine. First, it is necessary to find the steady flight-balancing tail load as existent from the unaccelerated forces of equilibrium on the airplane, the design speed of the airplane being used. In this connection the flaps-down attitudes must not be overlooked for, although the effect of the gust is small due to reduced speed, the original high balancing load may be enough to cause this attitude to be critical. This balancing load occurs before the advent of the gust and to it must be added that resulting from the gust or by reason of changes in angle of attack arising therefrom.

The gust promotes four tendencies to change the angle of attack. The changes may be considered separately, and later their additive effect determined. First, when the wings of the airplane enter the gust, a change in wing angle of attack occurs. This change results in a new down-wash angle of the air flow from the wings and gives one tendency toward a change in the angle of attack of the tail surfaces. Second, during the short time interval existing between the entrance of the wings into the gust and the entrance of the tail, a vertical acceleration of the airplane occurs and the resulting vertical velocity gives a change in tail angle of attack. Also, during this same time interval, an angular acceleration of

the airplane occurs and the third change results. Finally, there is the change in angle due to the advent of the gust itself.

It has been found, in general, that the second and third changes just given are negligible, or at least not within the normal error of assumptions, and therefore may be neglected. The two remaining changes are all-important, however, but the down-wash angle tends to relieve the severe effect of the gust proper. Summing up, then, a design load on the horizontal surfaces results from the combination of the original balancing load, the load occurring from the change in angle of attack from the gust proper, and the load occurring from the change in angle of down-wash. As with the fin, it is conservative and desirable to use the combined movable and fixed surface areas in determining the loads, to neglect the possible "free" elevator effect, and to apply the entire load to the stabilizer. The following formula gives the horizontal surface applied load increment resulting from the gust and down-wash:

$$\Delta_t = (0.1)\,(U)\,(v)\,(A_t)\,(s_t)\left(1 - \frac{36}{R_w}s_w\right)$$

~~two Eclopse gas-fired, salt-bath, pot furnaces having 10-in.~~

Δ_t = tail-load increment in pounds.
U = gust velocity in feet per second.
v = airplane velocity in miles per hour.
A_t = tail-surface area in square feet.
s_t = slope of lift curve of tail surface in C_L per degree.
s_w = slope of lift curve of wing in C_L per degree.
R_w = aspect ratio of wing.

(2) Ground-gust loadings. Experience resulting from gust loads while airplanes were being taxied or handled on the ground indicated some time back that large elevators and rudders were highly loaded from these gusts. Troubles particularly have arisen when airplanes were towed tail first around the corner of a building during a gale. Wind-tunnel tests conducted with the air stream acting forward on the surfaces corroborated the evidence of experience and gave unusually high hinge-moment coefficients. There is considerable need for further research on the subject as several difficulties were encountered in testing. However, the moment coefficients given in Table 2 are the most reasonable interpretations to suit the usual ground and surface angles and are now being used as design criteria until more exact information is forthcoming. Of course, the location of the stops or locks influences the amount of the surface designed by the gust conditions but, with the locks located at the mast or at the end of the torque tube, practically the entire surface (particularly the rubber) may be critical for airplanes above 50,000 lb. gross weight. It has been found extremely undesirable, in fact prohibitive from a weight standpoint, to locate the locks or stops in the cockpit because of the excessive forces that must be then transmitted through the control system and the resulting severe deflections. Design speeds for the ground-gust condition should be a least 60 m.p.h.

(3) Trim and servo "tab" loads. Although tabs on small airplanes do not present much of a problem as far as loads go, for large airplanes considerably more attention must be paid to the tab structure. This condition will be realized when it is considered that a servo tab for an airplane of 80,000 lb. gross weight may be approximately the size of the elevator of a 3000-lb. pursuit airplane. The main load on a servo tab is, of course, that imposed by the pilot and is computed readily. That for a trim tab is rather uncertain, but the use of the design speeds, together with most extreme-force and moment coefficients likely to occur, is probably the most desirable method at present. The Bureau of Air Commerce in Bulletins 7-A and 26 gives adequate rulings so that further explanation is not necessary here. However, rigidity of the tab supports is all-important, and the designer is confronted with some exacting problems to obtain the necessary rigidity at the trailing edge of a surface where, in the interests of static and dynamic balance, he least desires to spend any weight.

In addition to the problems of loading, tail-surface design also presents numerous problems in obtaining adequate rigidities. The necessity for divergent natural frequencies among the various surfaces and control systems generally is well realized at the present time. So far, vibratory tests on the movable surfaces have shown that their control-system frequencies may extend over a considerable range, that is, they do not have a definite peak but rather vibrate with approximately the same amplitude over a range of 200 to 400 vibrations per min. Also, elevator and rudder control-system frequencies are predominantly low. Thus it becomes extremely desirable in the interests of safety to maintain fixed surface frequencies above the band of critical values possible for the control systems. Likewise, it is necessary to keep the fixed-surface frequencies above the eddy frequency from the wings or possibly the landing gear. Now the tendency is for the fin and stabilizer frequencies to become lower with increased size. Therefore, to keep the frequencies high on large cantilever surfaces, special precautions must be taken with regard to stiffness, thickness, and design details.

Table 3 shows the frequencies of surfaces on airplanes of varying sizes. All surfaces were full-cantilever. For pur-

Table 2 – Moment Coefficients on Tail Surfaces for Ground-Gust Conditions

Surface	Position	Moment Coefficient In N.A.C.A. Units
Elevator	Neutral	1.00
Elevator	Full-Down	0.90
Rudder	Neutral	1.30
Rudder	Sidewards	1.50

Table 3 – Natural Frequencies – Tail Surfaces

Airplane Gross Weight, lb.	Surface	Unit Loading Based on Total Surface (Movable and Fixed Surface Area), lb. per sq. ft.	Unit Loading on Fixed Surface, lb. per sq. ft.	Natural Frequency, vibrations per min.
3000	Fin	96	208	1750
13000	Fin	29	72	1200
14000	Fin	32	80	900
30000	Fin	50	50	650
3000	Stabilizer	135	286	1400
13000	Stabilizer	54	95	1070
14000	Stabilizer	66	110	900
30000	Stabilizer	56	56	625

poses of comparison, the design loads also are given. The tendency of the frequencies to decrease with size is shown clearly. As an example, in the design of an airplane of say 80,000 lb. gross weight, studies have indicated that the fin and stabilizer frequencies would be low and undesirable if past practice in fixed surfaces were followed. Consequently, to obtain the frequencies in the desired neighborhood of 600 to 800 vibrations per min., it would become essential to employ greater thickness ratios and more material than otherwise was necessary.

Manufacturing Problems

The Boeing Co. has developed a system of furnishing templets and drawings to the shops for the construction of large aircraft where the engineering department makes all the templets and layouts in conjunction with their drawings and loft. This method of furnishing templets eliminates the duplication of layout effort on the part of the shops as the engineering department, through shop contact, strives to furnish the templets exactly as the shops would use them. Having the engineer make the full-size templet has a reaction upon engineering accuracy not always present in quarter- or half-size drawings where the engineer knows that the shops will have to lay out work to full size. At the time of templeting the engineer can determine offsets, laps in joints, number and spacing of rivets, and a dozen other small but important things which he cannot escape on the full-size templet and which he is best able to take care of.

A schedule of group release dates is agreed upon between the production planning department and the engineering department as being the outside date when all drawings and templets for that group will have been released. This scheduling is done so that production can anticipate and plan the shop schedules. In every group there are always several key parts which can be agreed upon with production planning and purchasing as parts that should be rushed through enough in advance to take care of the extra time required to obtain material and for the shops to process so as to have them ready to meet the required schedule. Taking the body groups of one bomber as an example, the front and rear wing-spar-attachment bulkheads were first in release importance with the steel heat-treated square tubing as key material to be ordered. The stabilizer, fin-and-rudder-attachment bulkheads were second, with the intermediate and supplementary bulkheads being third in release importance.

Templets

The following outline is written in explanation of the function of templets, developed by our engineering department, as a means of reference for use in the shops supplementary to the usual system of drawings:

The first step taken toward templet development for the body group at the time a new design is being released is the layout of body lines. This layout in most respects is similar to a ship mold loft. The fairing out and smoothing of the fuselage or hull shapes and contour are accomplished by this full-size development. In conjunction with this loft, elevations and plans are laid down as required to obtain true views, lengths, and bevels or slopes. The foregoing, as a master reference, permits the next step to be made which is that of transferring of lines and contours from the loft tables onto metal templets which are individual full-size layouts of the major transverse bulkheads, interspar beams, and so on. All detail parts of these structures appearing in the plan view will be shown on these full-size templets.

These templets, then, constitute the sole means of reference for the shops in the fabrication of parts and in the assembly of parts into the completed bulkhead or beam. All shops, whether they are concerned in the building of tools or fixtures or whether they are engaged in the manufacture of details or the operations of assembly, must at all times refer to these templets for information such as contour, radii, length, width, bolt size and spacing, rivet size and spacing, bevels, and slopes. It may be observed readily that such a common source of information minimizes loss of parts, time, and material. In addition to main-structure templets, are individual half-size templets of wing, aileron, landing flap, rudder, stabilizers, and so on, taken at designated stations which, in most cases, are normal to the chord plane of the wing or control surface. In general, templets are developed for use in the shops to convey contour, tapers, true views and any information which cannot be portrayed readily by drawings as directly usable information.

In conclusion it may be stated that, as an accurate, common source of reference, templeting of some sort is absolutely essential and especially is this statement true when dealing with a large class of aircraft.

Drop Hammer

In order to develop the maximum aerodynamic efficiency it is extremely important to manufacture efficiently dies and forms that will produce the many accurately faired lines and curves that are so necessary for the streamlined airplane of today. Since an order rarely exceeds 75 to 100 units, these

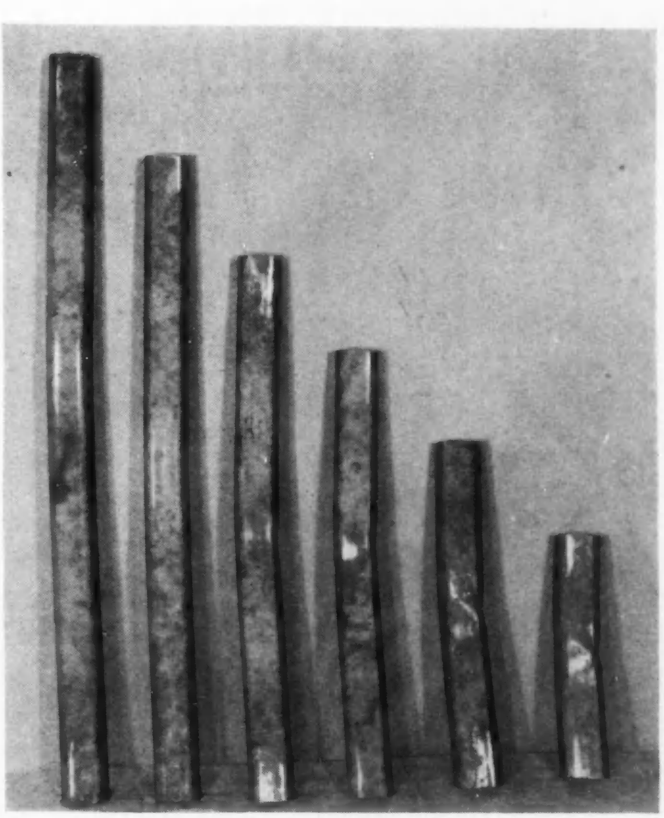


Fig. 13 – Column Test Specimens

forms and tools must be economical to produce as there are no long runs over which the cost may be amortized. One very efficient method for certain types of work is the use of zinc dies and lead punches in drop hammers.

The ordinary procedure with the drop-hammer method is to make a plaster cast of the die to be made, the shapes being developed through the use of loft templets from a mock-up, from a plaster model, or even from a "hand-made" part. This plaster cast is used as a pattern from which the zinc die is cast. The zinc die is then filled with molten lead which produces the punch. This procedure now gives us the die set which only requires that the faces be ground to allow clearance for the metal to be stamped in the die. When the required parts have been made, the dies are re-melted and the plaster cast is stored for future use if required for additional orders, spares, and so on. The foregoing is the general "drop-hammer" plan at Boeing.

During the early stages of the development of our drop-hammer method we were producing an all-metal plane of approximately 3000 lb. gross weight, and it was found that a drop hammer with a bed of 27⅜ in. x 30 in. and designed to handle a punch with a maximum weight of 3150 lb. was all that was required. We next manufactured a plane with a gross weight of approximately 13,500 lb., and it was necessary to provide a hammer with a bed size of 36 in. x 45½ in. and facilities for pouring and handling punches with a maximum weight of 4650 lb. This hammer served the purpose very well until we started building planes of 30,000 lb. and more, when we found it necessary to design and build a hammer with a bed 48 in. x 72 in. and capable of handling punches up to 11,625 lb. This hammer strained our pouring and

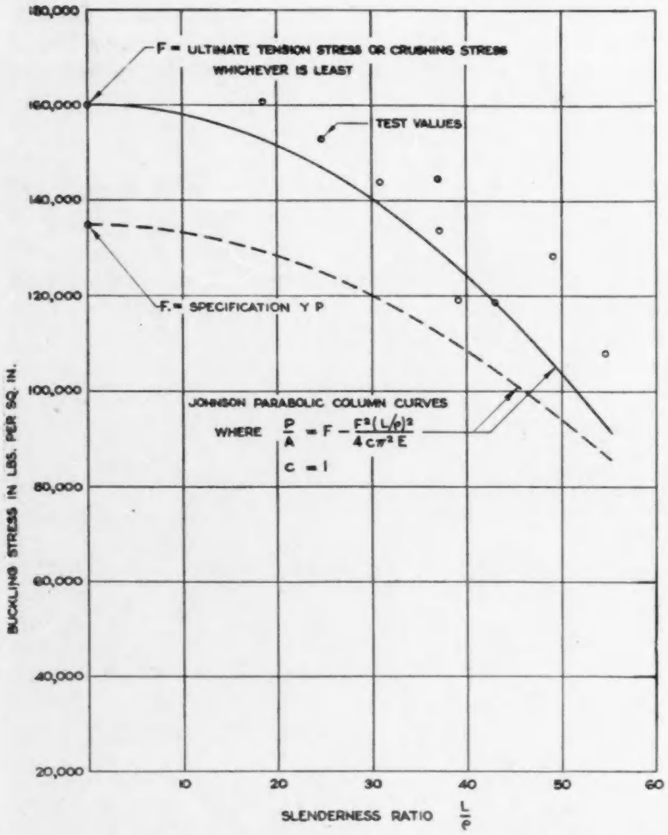


Fig. 14 – Column-Strength Curves – Square Steel Tubes, Heat-Treated

handling facilities to the utmost. At present our handling equipment consists largely of four-legged handling dollies which have chain blocks for the hoisting mechanism and run on casters. These dollies straddle the rows of dies in storage and run on steel channels on the floor as the wooden floors wear quite fast due to the heavy loads on the small casters.

With the equipment we now have, we can manufacture whole door frames and channels in one piece. We have made wing-root fairings in one piece that are 11½ ft. long by 17 in. in width by using lead and zinc dies in our 700-ton capacity hydraulic press. These fairings do not require a great deal of forming but would be very hard to fabricate by any other method without resorting to "shingling", which does not produce the smoothly faired lines we require. It is believed that we now have equipment that will take care of all future needs even though planes of 100,000 lb. and more were to be constructed. Extremely large parts will have to be spliced, however, as there is an economic limit in connection with die cost and handling.

Fig. 16 illustrates the installation of the three hammers mentioned in the foregoing and the handling dollies and several types of parts that have been produced by this method.

Steel Heat-Treatment Facilities

The present trend toward larger airplanes calling for the use of alloy-steel parts of higher tensile strength in both increasing sizes and numbers has been met at the Boeing Aircraft Co. by a modernization program in its heat-treatment department.

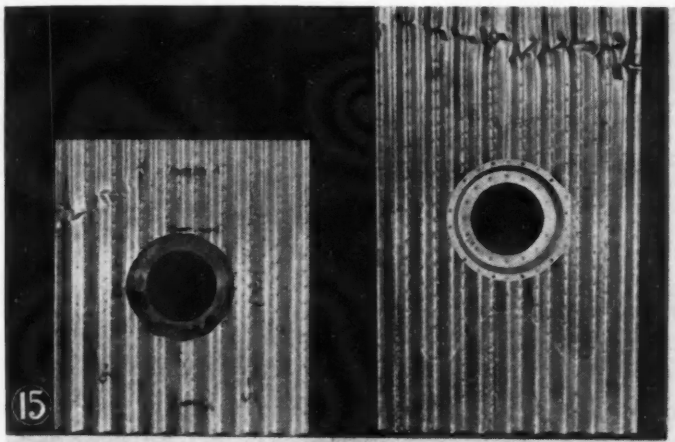
In carrying out this program our heat-treatment department was completely rearranged and expanded into a room 38 ft. by 40 ft. This room is adjacent to, and under the supervision of, our machine shop.

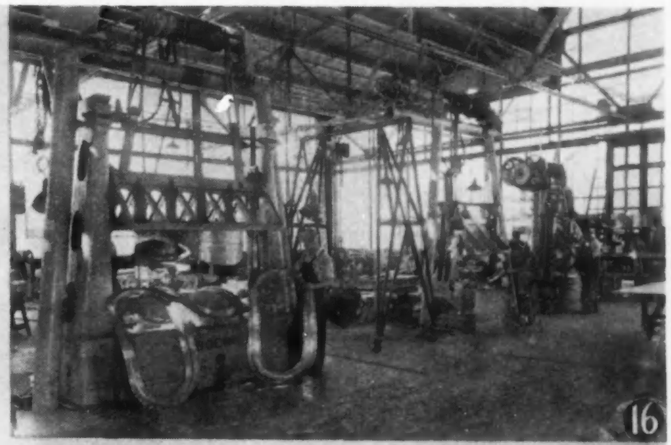
The new equipment added to the department includes two Hevi-Duty electric furnaces, one an atmosphere-controlled hardening furnace and the other a fan-circulated air-draw furnace. Both of these furnaces have interior working dimensions of 4 ft. by 8 ft. long by 2 ft. high. The atmosphere controller used in conjunction with the hardening furnace has a capacity of 1400 cu. ft. of gas-air mixture.

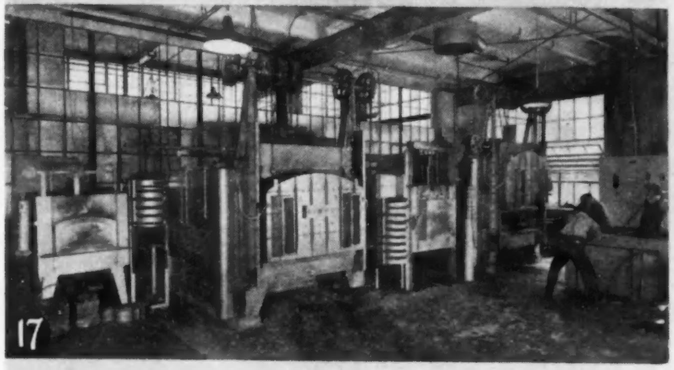
The power rating of the hardening furnace is 150 kw., and that of the air-draw furnace 95 kw. The maximum operating temperature rating of the hardening furnace is normally 1850 deg. fahr. but, when used with atmosphere, this temperature can be increased to 2000 deg. fahr., for short periods of time without damage to the heating elements. The air-draw furnace has a maximum rating of 1250 deg. fahr.

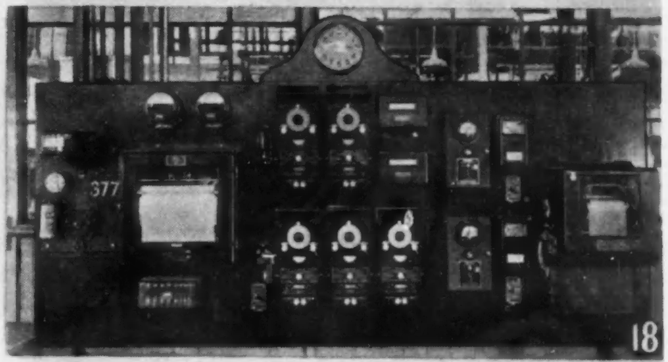
Arranged in the room with these two new furnaces are several pieces of older equipment including two Hoskins furnaces, one 6 ft. long and the other 10 ft. long, both having a cross-section of 20 in. wide by 12 in. high inside; (see Fig. 17) two Eclipse gas-fired, salt-bath, pot furnaces having 10-in. diameter by 16-in. deep pots, arranged for cyanide hardening; and one small Stewart gas-fired, semi-muffle tool furnace.

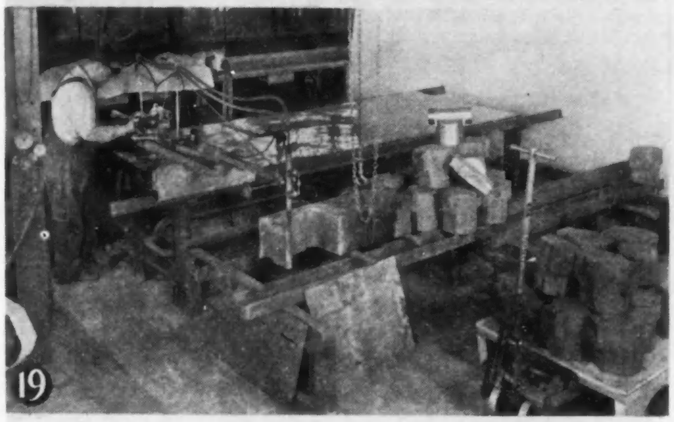
The auxiliary equipment includes one large oil-quenching bath 5 ft. wide by 11 ft. long by 32 in. deep inside, water-jacketed and air-agitated, and arranged to serve both the Hevi-Duty hardening furnace and the 10-ft. Hoskins furnace; a water bath for the cyanide furnace; a combination oil and brine bath for the tool furnace and a portable water bath for the large furnaces, used only when oil does not give a sufficient hardening rate.

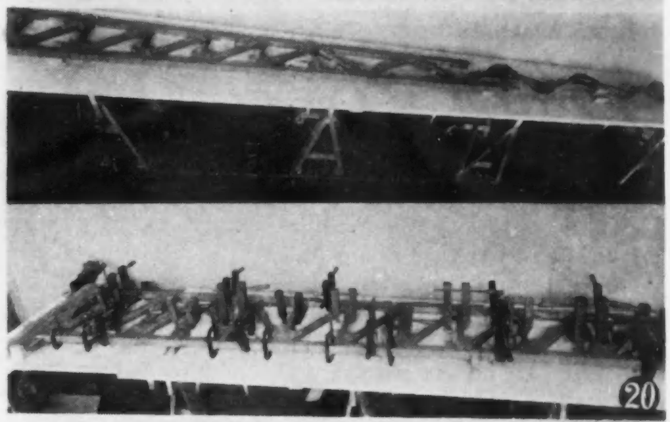


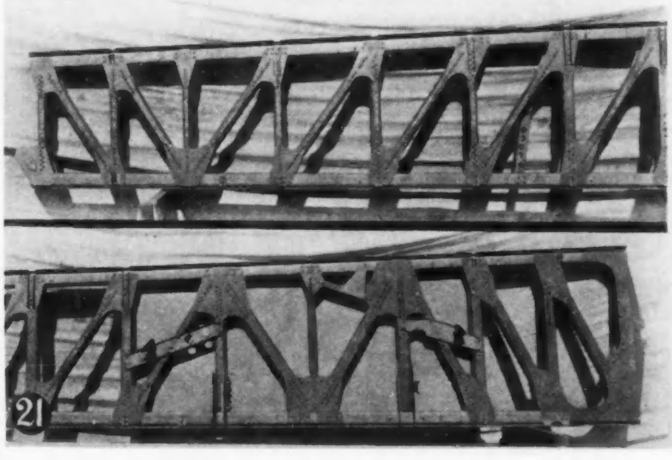












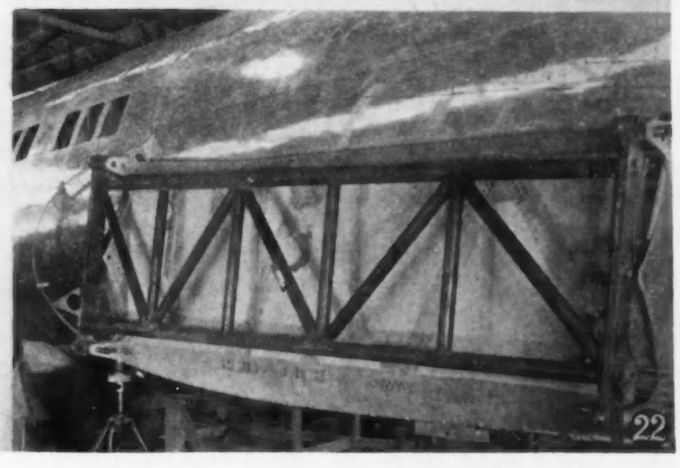


Fig. 15 – Reinforcings – Corrugated Panels

Fig. 17 – Heat-Treating Furnaces

Fig. 19 – Burning Operation – Oxweld Cutting Torch

Fig. 21 – Spar Assemblies

Fig. 16 – Drop Hammers Showing One-Piece Door-Frame Set-Up

Fig. 18 – Control Panel – Heat-Treating Equipment

Fig. 20 – Spar Construction Methods

Fig. 22 – Wing-Connection Mating Jig

All instruments and furnace-control devices are mounted on a single panel 9 ft. by 7 ft. high, located opposite the electric furnaces (see Fig. 18). This panel includes a Wilson-Maeulen indicating pyrometer with a 20-point switch arranged to indicate temperatures at one or more points in all of the furnaces. A Foxboro potentiometer recording pyrometer maintains a record of the temperature at two points in both of the Hevi-Duty furnaces and the 10-ft. Hoskins furnace. Five Foxboro potentiometer control pyrometers automatically control the temperatures of these three furnaces, there being two zones for temperature control in each of the Hevi-Duty furnaces and one in the 10-ft. Hoskins furnace. Two Lindberg input-control instruments control the rate of heat input to the two Hevi-Duty furnaces and two Hevi-Duty excess-temperature cutouts protect them against overheating in case of failure of the control instruments. Three electric time switches are used for starting or stopping these furnaces at predetermined times when unattended. A Wilson-Maeulen Tapalog recording pyrometer is connected to the 6-ft. Hoskins furnace, the three Eclipse pot furnaces, and the Stewart tool furnaces. A General Electric clock is mounted at the top of the panel and the power company's two wattmeters are arranged conveniently to give the total power consumption for the heat-treatment room.

Electric power supply to the heat-treatment room is furnished by three 100-kva. transformers installed by the power company just outside the building. Here power at 26,000 volts is stepped down to 250 volts, 3 phase, and brought into a new distribution panel. This power for the furnace is kept separate and does not interfere with the main power supply to the plant. City gas having a heat content of 505 B.t.u. per cu. ft. is used in the gas-fired furnaces and also the atmosphere controller for the Hevi-Duty hardening furnace. This gas is brought in at 15 lb. per sq. in. pressure and reduced through governors where necessary.

The atmosphere controller can be operated on quite a wide range of air-gas ratio but a ratio of 2½ parts air to 1 part of city gas, giving after combustion an atmosphere containing 8 per cent carbon monoxide, has been found to give best results with the S.A.E. 4130 and S.A.E. 4345 steels we are now using. This atmosphere seems to give minimum decarburization with minimum scaling.

A test of the temperature distribution throughout the working chambers of the two new Hevi-Duty electric furnaces was made shortly after their installation. This temperature distribution was found to be very uniform, in fact, the variation in several thermocouples located at various points throughout the chamber fell within the expected variation between individual thermocouples when checked at a given temperature with the same instrument.

On account of the uniformity of temperature distribution, the air-draw furnace is being used for annealing duralumінum during the night. The furnace is loaded just before the end of the day shift, and the input control is set to give the desired rate of temperature increase. When the proper annealing temperature is reached, the control pyrometers check and hold it constant over the soaking period when the time clock shuts off the power. The natural cooling rate of the furnace provides the proper rate of temperature decrease so that, by morning, the load is down and can be removed safely.

Handling equipment for the heat-treatment room consists of a 500-lb. air hoist and trolley suspended from a monorail running the length of the room in front of the furnaces and over the large oil-quench tank. This hoist is supplemented by a steel table on large casters, its top being level with the furnace hearth (the large quench tank is located directly in front of the Hevi-Duty hardening furnace, the top edge of the tank being level with the hearth) so that, by bridging between the two with a portable steel plate, heavy steel parts may be loaded easily into the furnace or withdrawn for quenching.

Machined Fittings

The following is an outline of the various and intricate operations required in making a landing-gear-strut terminal of S.A.E. 4130 steel for a 30,000-lb. airplane:

From a 9¼ in. x 12 in. billet, parts are burned to within ¼ in. of finished dimensions on an Oxweld pantograph burning machine. (See Fig. 19 showing burning machine, burned-out and partially-machined parts.) These rough-burned parts weigh approximately 180 lb. each. Had hacksawing been employed to cut these parts from the rough bar instead of burning, the parts in the rough would have weighed 314 lb. each. The savings incurred by using this method become apparent for the following reasons: 134 additional lb. of metal would have to be removed by machining if the parts were not burned to shape. This additional metal would be scrap in planer chips, and so on. Parts are nested by the burning method, leaving only a thin wall of metal between them. About 2¼ hr. are required to burn one of these parts and, owing to the shape of them, it is safe to say that at least 24 hr. of machine time is saved, to say nothing of the material saving alone.

The operations subsequent to burning are: Normalize at 1650 deg. fahr. for 2 hr. Sandblast, flash-plate, and check for cracks. If no cracks are found, the part is set up in a fixture on a 28-in. No. 4-A Warner & Swasey turret lathe and the 7½ in. diameter turned to within ⅛ in. of finished size. (This ⅛ in. is removed after heat-treatment.) The bore is finished and the ends faced. The inside bosses are machined with a 2-in. end mill on a No. 3 Cincinnati vertical milling machine. The terminal end is rough-bored, faced, and turned on a No. 41 Lucas boring mill. The width and 60-deg. angle are cut on a No. 3 Cincinnati horizontal milling machine. The part is next mounted on a power-driven rotary table on a No. 3 vertical mill, the 8-in. diameter and relief on top of the terminal are then milled. Again the part is flash-plated, and checked for flaws. If found O.K., the plating is stripped preparatory to further machining. All sharp corners and radii are hand-finished before heat-treatment to remove tool marks.

The next operation finds the part in a Hevi-Duty automatically temperature-controlled electric furnace at 500 deg. fahr. The temperature is then raised to 1200 deg. fahr. in 1 hr. The part is now transferred to a high-heat atmosphere and temperature-controlled furnace and the temperature gradually raised to 1625 deg. fahr. The part is then quenched in oil to room temperature, cleaned, re-heated to 950 deg. fahr., held at that heat for 2 hr., and cooled in air. This treatment produces 150,000 lb. per sq. in. tensile strength. After heat-treatment follows sand-blasting, plating, microscopic checking for flaws, finish-turning, facing, and threading in an engine lathe. The bore in the terminal end is finished in a Lucas mill; bushings are pressed into the bore

and are likewise bored in the same machine. Bolt holes are jig-drilled. The final coat of plating is applied and inspected for flaws. Last, comes final inspection of workmanship. Finished weight of part is 41 lb. including the bushings.

The following description covers in general the operations involved in making a pair of landing-gear links from chrome-nickel-molybdenum steel, S.A.E. 4345:

Rough-hammered forgings were used, weighing 495 lb. each, and procured from the General Metals Corp., Los Angeles, Calif. Upon receipt these forgings were pickled, plated, and checked for flaws. They were then machined to a finished weight of 55 lb., a reduction of 440 lb.

The sequence of operations follows: All surfaces were roughed out as far as possible on a planer, then set up on a Lucas boring mill and the flanges rough-faced and the bore roughed out to 3½-in. diameter. The links were then set up on a Warner & Swasey turret lathe, and terminal ends rough-turned and bored to within ¼ in. of finished dimensions, and brake flanges finished on the inside faces. All outside surfaces were then rough-profiled on a rotary table on a Lucas boring mill. The links were then plated and checked for flaws and defects in material, then replaced in the Lucas mill which was left oversize due to a decimal dimension. All surfaces and radii were then hand-ground with a Kipp Grinder to remove tool marks. Again the fittings were plated, checked for material defects and stripped of plating preparatory to heat-treatment. (All decimal dimensions are finished after heat-treatment.)

The semi-finished links were then placed in a Hevi-Duty atmosphere and temperature-controlled furnace at 500 deg. fahr. and the temperature raised to 1200 deg. fahr. in 1 hr. Then a controlled atmosphere of 8 per cent CO was introduced and the temperature slowly raised to 1475 deg. fahr. where it was held for 1 hr. The parts were then quenched in Houghton's No. 2 oil to approximately 500 deg. fahr., then transferred to a drawing furnace, the temperature of which is 500 deg. fahr. The temperature was raised gradually to 850 deg. fahr. and held at this heat for 4 hr., then the parts were quenched in oil to room temperature. A Brinell hardness between 375 and 415 was required to insure a tensile strength of 180,000 lb. per sq. in.

After heat-treatment, the parts were sand-blasted, plated, and checked microscopically for cracks. A repetition of the machine work done previous to heat-treatment followed, except that all dimensions were finished to drawing. Finally, the parts were plated and inspected for material defects and workmanship.

Construction of Spars

The fabricating of spars from square-section tubing in small lots does not permit the use of elaborate jigs. Some simple method of building spars had to be devised. This problem was met successfully by the use of flat wooden tables of work-bench height. (See Fig. 20.)

The tops of these tables are painted white, and an accurate full-sized layout of a spar is made on them, including chords, vertical members, diagonals, and gussets. Blocks are secured to the table to hold component parts in their proper locations.

Gussets are drilled with pilot holes into which pins in the table are fitted for holding the gussets in place.

Chords, diagonals, verticals, and gussets are placed on the table between holding blocks and clamped together. While set up in this manner, holes are drilled in structural members through the gussets from top to bottom. Temporary sheet-metal screws are used to hold members in place preparatory to riveting.

The chords are then removed to admit bucking bars into verticals and diagonals and gussets are riveted permanently to the same. This part of the spar is called the web.

A table is likewise used for locating and drilling the spar caps on upper and lower chords. After drilling the spar caps are riveted to the chords.

The chords with spar caps attached are replaced on a table with completed web, and rivet holes are drilled in chords and fittings. Temporary screws are placed in enough holes to hold the structure together. This entire section is then removed from the layout table and is riveted completely.

A spar usually is made up of four sections, similar to the one described, and joined by close-fitting inserts which, in turn, are riveted into chords. On the completed spar there are nearly 1000 fittings of 100 different kinds. These fittings are misplaced easily due to their similarity and cannot always be changed as they are riveted onto the web and are closed in after the chord is riveted into place. Spar assemblies are shown in Fig. 21.

Jigs, Gages, Fixtures

Jigs and fixtures of extreme accuracy are required in the construction of aircraft to insure interchangeability of component parts.

Some of the most important connections are: wing to fuselage, wing to wing tip, aileron to wing, nacelle to wing, landing gear to wing, fuel tanks to wing, stabilizer to fuselage, elevator to stabilizer, rudder to fuselage, and innumerable other mating parts all of which require jigs, gages, and fixtures.

The particular phase of jig and fixture work described here will be confined to the inboard wing and its attachment to the fuselage.

The first step is the making of master drill plates. Taper-pin holes are located definitely on these plates from engineering drawings of wing connections. Straight holes are then bored in these plates on a jig borer, to tolerances of +0.0005 in., −0.0000 in. Hardened and ground liners are then pressed into these drill plates. The inside diameter of these liners is 1/32 in. below the small diameter of the taper pins used.

Male and female mating jigs are checked together before being released for use on assembly jigs.

After terminal-locating fixtures have been secured to body and wing jigs, they are proved for alignment by placing male mating gages in female terminals on the wing. Straight-ground pins are inserted into the holes insuring that the product of one jig will fit into the product of the other. When several jigs of the same kind are to be built, the reason for these mating gages becomes obvious.

Upon completion of a body and wing the fixtures employed to hold terminals are removed. The wing is transported from the wing shop to the body shop, and wing terminals are slipped into terminals attached to the body. Straight-ground pins are then driven through the interlocked terminals.

One by one these pins are removed and the reaming of the taper-pin holes is accomplished by the use of a special spiral piloted taper reamer, the pilot of which is a nice running fit in the straight holes in the wing and body terminals, thereby

keeping holes in one plane. (See photograph of typical wing-connection installation Fig. 22.)

Conclusion

This paper has dealt only with a few of the many problems involved in the design and construction of large aircraft. It is believed that the title of this paper might well have been "Design and Construction of Larger Aircraft" because the airplane which today appears large will, no doubt, be but a stepping stone to airplanes of immense proportions. With increased size the present-day fuselages which have a certain relative size, as measured in terms of the airplane's overall dimensions, will disappear. It is quite easy to imagine, for instance, wings in which powerplants are housed entirely within the wing contour, and cargo, passenger, or military requirements also will be contained within the center section without external enlargements such as we now see as the fuselage.

It also is believed that the flying boat has no limitations as to size at the present time, and that much greater progress will be made in the future toward enlargements of this type of airplane. It must be realized that funds for the development of engines and airplanes will be the real aid to rapid development of larger aircraft.

A large airplane entails so many phases of engineering that it is impossible to elaborate in a paper of this length on the many problems involved. It is hoped that the problems discussed herein will give some idea regarding the methods of approach in designing a large airplane and the various manufacturing obstacles that have been overcome.

Discussion of Minshall-Ball-Laudan Paper

Compares Various Methods of Solving Problems

—Edward F. Burton
Chief Designer, Douglas Aircraft Co., Inc.

THE large payload and commodious accommodations available from large airplanes justify their construction even with all the accompanying problems. The favorable influence of increasing Reynolds number upon drag, lift, and wing planform is received most gratefully and depended upon. The largely unfavorable influences of size upon structure, control, and manufacture are realized, but are being overcome slowly.

The lightness of controls on present airplanes up to weights of about 30,000 lb. indicates that, with or without the use of tabs, manual operation of controls can be made satisfactory for very large airplanes. Ground-handling of large airplanes is realized to be of greatest importance, so that methods are now being investigated for greatly increasing ground maneuverability. Newly developed servo hydraulic brakes now in service seem to offer considerable gain in ground-handling ability.

The efficiency of a structure depends largely upon its state of development. Although the truss-type spar has been chosen in the paper under discussion, recent research, calculations, and tests indicate that the Wagner (sheet-shear-web) type of beam offers advantages in economical construction, simplicity, and light structural weight. It should be noted that the full efficiency of the Wagner type of construction often is overlooked when calculated by the simple theory, since secondary actions of the web have been found to contribute as much as an additional 100 per cent to the strength of the beam.

It is becoming widely accepted knowledge that corrugated-sheet construction has greater strength for a given weight in many applications than does the stiffener-sheet arrangement. This increase in structural efficiency has appeared at just the right time to offset part of the wing weight increase for large airplanes. The higher stresses give large tip deflections but this does not seem to be any great disadvantage providing torsional deflections are small. A serious trouble with corrugations is that they make detail design of joints, attachments, and fittings very difficult.

The use of the mold loft becomes more important due to increase in size of such items as fuselage frames, wing ribs, and beams. Full-size lofted parts can be held very accurate. The use of coordinating holes in fabricated parts simplifies assembly problems and allows the manufacturer to reduce the number of fabricating jigs.

Most factory equipment increases in size with the airplanes. Such equipment as sheet-metal power brakes, drop hammers, hydraulic presses, anodic tanks, heat-treating furnaces, and plating tanks must be of increased size. As the airplane grows to enormous sizes, to which there is believed to be practically no limit, the manufacturer will be faced with a problem of combining present aircraft-manufacturing practices with ship-building practices.

The use of heat-treated castings will simplify the manufacture of many large fittings that otherwise would have to be fabricated from a number of smaller parts welded together, which method is not very satisfactory in highly stressed parts. The other method of machining such fittings from billets is very costly and not altogether satisfactory as the heat-treatment generally is not uniform due to heavy sections being adjacent to thinner sections. Fittings machined from billets generally run overweight due to the complexity of machining, consequently with use of the X-ray and improved foundry methods it is hoped that the steel casting will be the solution.

One of the most serious problems that must be solved hurriedly is the development of engines of great horsepower (from 2000 to 5000 hp.) and of compact dimensions. Since there seems to be no need for more than four engines, and often need for only two, the necessity for engines of high power rating is obvious.

In general the problems and their solutions in the design and construction of large aircraft are common to all constructors, and the efficient solutions of these problems seem near at hand even though by somewhat differing means.

Two Controversial Points Discussed

—Elliott Gray Reid
Professor of Aerodynamics, Stanford University

THE authors of this paper certainly have described some of the most interesting as well as the most controversial problems of the design of large aircraft. I would like to comment upon just two of them.

It would be interesting to have a more complete explanation of the statement that "It is also evident that greater liberties may be taken with planform taper, since stalling of the tips of large aircraft will not be so predominant as with small airplanes . . ." because it appears impossible to justify this conclusion without making the assumption that lift-curve discontinuities become less abrupt with increasing Reynolds numbers. Although this condition is true of some airfoils, particularly in the small Reynolds-number range, the behavior of some of our most useful profiles at large Reynolds numbers is contradictory to this assumption. (A case in point is the 23012 airfoil; test results are presented in N.A.C.A. Technical Report No. 530.) Therefore, in the absence of qualification or further explanation, the statement referred to seems to be an inaccurate generalization.

Another point upon which there may be some difference of opinion is the best method of preventing control-surface flutter. The proponents of irreversible controls have a strong argument in the absurdity of building a light and efficient aircraft structure and then loading it with lead to prevent vibration. However, those who favor static balancing insist that an irreversible control system weighs more than a plain one, that net control-system weights need not be excessive if static balance is obtained by proper disposition of the required structure with respect to the hinge line and, finally, that their method eliminates the evil at its source rather than simply holding it in check. With typical English caution, Frazer and Duncan, in their celebrated study of flutter, recommend the adoption of both measures whenever practicable. Since most designers consider either one or the other sufficient, some additional discussion of their individual merits would seem in order at this point.

Gust Loads on Airplanes

By Richard V. Rhode
Aeronautical Engineer, National Advisory Committee for Aeronautics

THE concept of a "sharp-edged" gust in which the wing is assumed to obey the laws of steady flow has proved useful as a temporary expedient in setting up design criteria for gust loads. However, the trend toward construction of large, heavily loaded transport airplanes and the problem of the light airplane require further rationalization of these criteria.

Present indications of extensive acceleration data obtained on the relatively small transports of the domestic airlines and on the large Clippers of the Pan American Pacific and Caribbean routes harmonize with theoretical indications that current design criteria are under-conservative for heavily loaded airplanes and over-conservative for lightly loaded ones. Occasional records of acceleration in very strong gusts, such as occur in line squalls, emphasize the necessity for avoiding severe weather conditions.

THE highly complex character of the gust-load problem and the lack of knowledge of gust structure have led to the general use of gust-strength criteria for airplane wings that are based on the concept of a "sharp-edged" gust in which the aerodynamic phenomena are assumed to obey the laws of steady flow. According to these assumptions, the increment of applied load factor experienced by an airplane flying from calm air into a gust blowing normal to the flight path may be expressed by the following relation[1]:

$$\Delta n = \frac{\rho\, a\, UVS}{2W} \qquad (1)$$

in which Δn is the increment of load factor
ρ, air density,
U, gust velocity,
V, airplane velocity,
S, wing area,
W, weight of airplane,
a, slope of wing-lift curve per radian.

[This paper was presented at the Annual Meeting of the Society, Detroit, Mich., Jan. 14, 1937.]

[1] See N.A.C.A. Technical Note No. 374, April, 1931; "Preliminary Study of Applied Load Factors in Bumpy Air," by Richard V. Rhode and Eugene E. Lundquist.

[2] The effective gust velocity is the fictitious value calculated from acceleration and air-speed measurements through the medium of the sharp-edged gust formula.

In this country the intensity of the sharp-edged gust used in design has been derived from early acceleration data supplemented by information from meteorological sources. It has a value of 30 ft. per sec., which is in substantial agreement with the values used in other countries. Since this value was selected, the acceleration data have been extended and, moreover, these later data have been correlated more closely with the air speed so that, not only can a better determination of the arbitrary gust velocity be made, but also the dependence of the probable maximum gust values on the speed can be determined. The first object of this paper is to present these new data for the information of designers and others to whom they may be of interest.

Experience and qualitative considerations indicate that the practice of using what we have called "effective gust velocities"[2] based on measurements on transport airplanes with moderate wing loadings leads to unreasonably severe design factors for light airplanes. There are also some grounds for believing that the same practice may lead to unconservative values for heavily loaded airplanes, a possibility that may be of considerable importance at this time in view of the trend toward large airplanes with high wing loadings. It is not my intention to attempt to prove that these statements are necessarily true, but merely to present some rather limited data and theoretical curves that appear to support them.

Air-Speed Acceleration Data

The N.A.C.A. V-G Recorder. – This recorder, with which the data have been obtained, is an instrument designed to scribe a continuous record of the simultaneous values of air speed and acceleration experienced by the airplane in which the instrument is mounted. Fig. 1 shows this recorder and illustrates diagrammatically the manner in which it operates. Since the load factor (or acceleration in terms of gravity) is:

$$n = \frac{L}{W} = \frac{C_L(\frac{1}{2}\rho_o V_i^2)}{\frac{W}{S}} \qquad (2)$$

in which expression the symbols have their standard significance, it is clear that, when the wing loading of the airplane is known, the V-G recorder provides the information required for a complete picture of the load experiences of the airplane. That is, with n, $\frac{W}{S}$, and V_i known, the value of C_L, upon which the load distribution depends, is determined. In practice, when the instrument is left in the airplane for an extended period of operation, an area on the smoked record